
Cockpit Display of Traffic Information: Airline Pilots' Opinions About Content, Symbology, and Format

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COCKPIT DISPLAYS OF TRAFFIC INFORMATION: AIRLINE PILOTS' OPINIONS
ABOUT CONTENT, SYMBOLOGY, AND FORMAT

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INTRODUCTION

Within the next 10 years the projected availability of direct address beacon systems (DABS), beacon collision avoidance systems (BCAS), and inexpensive electronic displays will make it operationally possible to provide pilots with computer-generated cockpit displays of traffic information (CDTI). It has been suggested that such displays could provide a mechanism for "distributing the responsibility for certain ATC functions between the cockpit and ground ATC facilities" (ref. 1, p. 4).

Some of the fundamental questions concerning the benefits and liabilities of providing traffic displays in the cockpit have been studied by, among others, the Massachusetts Institute of Technology (ref. 2), Ames Research Center (ref. 3), and the Boeing Commercial Airplane Company (ref. 4). There are questions, however, "within both government and industry as to the extent to which both benefits and liabilities of CDTI could translate into the real operational environment" (ref. 1, p. 2). Although research has shown that pilot control in longitudinal spacing and pilot awareness of the traffic situation can be improved if traffic information is provided, the effect of CDTI on pilot and controller workload and the pilot's ability to assess such displays while performing his primary duties, have not yet been determined.

A series of assumptions, on which the current study was based, was made about the environment into which CDTI would be introduced and the initial roles that the pilot and controller would assume. It was assumed that CDTI will not become generally available until 1985. Its introduction will be evolutionary and will result in an initial mix of CDTI-equipped aircraft with those that are not so equipped. The information displayed will be ground-derived and transmitted by data-link. The CDTI will not be used as a primary collision avoidance system; it is assumed that the automatic traffic alerting and resolution system (ATARS), or a similar system, and the conflict alert system (CAS) will be available and will perform that function.

The initial functions that a pilot would perform with a CDTI would be essentially passive, such as traffic monitoring, but might include maintaining longitudinal separation when in-trail and when merging. ATC would still be responsible for separation, and the pilots would still respond to clearances and vectors from the ground. The display should provide a pilot with an awareness of his own situation and that of other nearby aircraft so that he

could detect loss of separation and ATC or airborne system failures. In addition, a CDTI would assist the pilot in evaluating the intentions of other aircraft and would allow him to anticipate and plan ahead. Following the initial introduction of CDTI into the ATC system, the division of responsibility between the air and ground might be modified even further with the pilot of a CDTI-equipped aircraft assuming more responsibility for separation and spacing.

To perform any type of ATC functions from the cockpit, it may be necessary to display weather, routes, terrain, and the status and intent of other aircraft in addition to the position of other traffic. Pilots now obtain such information from a variety of sources, including ATC, charts, weather radar, monitoring the radio transmissions of other aircraft, and simply looking out of the window. A CDTI could integrate these different types of information into a single multifunction display to assist pilots in forming a cognitive representation of the environment. Many questions remain, however, concerning what information should be displayed, in what format it should be presented, and with what level of complexity.

In order to determine the feasibility of the CDTI concept, extensive laboratory, simulation, and inflight research must be conducted. Because the design of the candidate display(s) used for research purposes could have considerable effect on the validity of the conclusions drawn about the feasibility of the CDTI concept itself, it would be desirable to design an optimal display in advance of the full-mission research. Although different displays have been used in previous research efforts, no systematic effort has been made to optimize display content, symbology, and format.

Because there is so much information that could be presented on a CDTI, and so many ways and combinations of ways in which it might be presented, elimination of obviously unacceptable alternatives in advance of laboratory and simulation research, in which the feasible alternatives would be evaluated experimentally, was deemed necessary. Because pilots will be the ultimate users of CDTI, they should be involved in this initial stage of designing the displays to be used in simulation research. To this end, numerous candidate displays were devised and simulated with a computer graphics system. These static displays incorporated different categories of information (e.g., traffic, weather, terrain, and route structure), presented with varying levels of complexity, symbologies, and formats. The candidate displays were shown to groups of airline pilots who were asked to evaluate, individually and in combination with other display elements, the specific features that they were shown. They were asked to specify the display content and format that would incorporate all of the essential information presented in an optimal fashion with minimal display clutter and confusion.

It was not intended that this study would result in the design of a single CDTI display, but rather that it would define the information that the potential user-population felt should be incorporated into a CDTI with preferred symbology and format. Those recommendations could then be used as the basis for laboratory research in which the preferred display features would be tested with dynamic simulations to determine which symbologies, formats, and combinations allowed accurate and efficient performance with acceptable levels of pilot workload.

METHOD

Subjects

Twenty-three commercial airline pilots based in the San Francisco Bay Area served as paid subjects in the study. Nine of the pilots were captains and 14 were first officers; total flight hours ranged from 5,000 to 20,000. All but three had military flight experience. Eighteen of the pilots had flown B-727's or B-737's; 14 had flown B-707's or DC-8's; and 6 were flying B-747's, DC-10's, or L-1011's. Four of the pilots also were active general aviation pilots. Sixteen of the pilots had previously participated in research at Ames Research Center, although only four of them had been involved in a simulation of traffic displays.

To avoid any bias in pilot selection, prospective study subjects were not told that CDTI was involved. Prior to the beginning of the study, the pilots were asked whether they were familiar with the concept of CDTI and whether they felt that the addition of graphically displayed traffic information to the cockpit would be desirable. Although only 8 of the pilots were somewhat familiar with the concept of CDTI, 16 of them felt that the addition of traffic information to the cockpit might provide useful information. The remaining pilots responded that they did not know enough about CDTI to form an opinion.

Procedure

The pilots were divided into three groups, two with eight members and one with seven, so that the candidate displays were shown to a number of pilots at the same time. Upon their arrival, the pilots filled out a brief summary of their professional experience (which is summarized in the "subjects" section). Instructions were read to each group describing CDTI, the environment into which it would be introduced, the tasks that pilots might perform with a CDTI, and the effect that it might have on the division of responsibility between the air and ground.

Presentation of the displays and the pilots' responses were divided into seven segments in which the display format, symbology, and content for a specific category of information was investigated. The different categories of information, displays, and questions were presented in the same order for all three groups: (1) navigation; (2) terrain; (3) own aircraft; (4) other aircraft (rules for display, symbology, coding schemes, data blocks, or tables); (5) weather; (6) the use of color; and (7) general questions. A brief introduction about each category of information and all of the relevant displays were presented before the questions for that category were read aloud by the experimenter so that all of the pilots in the group answered each question at the same time. They were allowed to ask questions at any time and were shown the displays a second time at their request. The pilots were given as much time to respond as required and they were encouraged to make written comments, additions, substitutions, and deletions to the display examples that they had

been shown in order to develop a set of display specifications that were representative of their opinions.

To protect the privacy of the individual pilots and of the airlines they represented, their names were not written on the response booklet, and responses were reported in summary form only. Most of the pilots did, however, provide their names and addresses separately because they wished to receive a copy of the final report and are planning to participate in subsequent studies.

Survey Format

Each pilot was given a 12-page booklet in which the items to be evaluated were organized into 7 sections that contained the specific questions that the pilots were to answer, directions about how to respond to each question, spaces for their responses, and additional space on each page for their comments. Several different response formats were used: (1) the pilots were asked to respond to an item by stating "yes" or "no"; (2) they were asked to indicate whether a specific feature was acceptable, individually, with no comparison to be made between alternative concepts, symbols, or formats; (3) they rated items individually by specifying whether it was necessary, desirable but not necessary, not needed, or not wanted; and (4) the pilots selected the one option that they preferred from a set of alternatives.

Test Materials

More than one-hundred sample displays were created to depict different CDTI concepts individually and in the context of a basic navigation display alone or in combination with other environmental information. Display content, symbology, and format were varied for each category of information, with and without color coding of individual elements. The scenario used in designing the displays represented a standard southern approach to runway 30L at San Jose Municipal Airport in San Jose, California. This was chosen because all of the pilot-subjects were based in the San Francisco Bay Area and were, therefore, familiar with the airport, its environment, and standard approaches. The approach was simulated for a medium-size jet at an initial distance of 50 miles from the airport at 15,000 ft, heading 302°, with a ground speed of 280 knots.

The displays were drawn with the magnetic pen and pad input device of an Evans and Sutherland Picture System II. This calligraphic system provided five colors (of which, in the interest of maximum contrast, only red, green, and yellow were used), variable line intensity, continuous scaling and rotation of displays and individual display elements, and alphanumeric characters. The drawing area in which the displays were created was 20.32 cm (8 in.) by 20.32 cm (8 in.). Individual display elements, such as aircraft symbols, route structure, and terrain features, were stored as individual frames, which could be recalled and combined in different ways with different scales, orientations, and colors to produce the set of candidate displays used (ref. 5). The displays were photographed and 35-mm slides were prepared for presenting

the CDTI options to each of the groups of pilots who participated in the study. The pilots' viewing distances ranged from 1.52 m (5.0 ft) to 3.02 m (10.0 ft). The size of the projected displays was 35.6 cm by 35.6 cm (14.0 in. by 14.0 in.). Proportionally, the average display area was equivalent to that of a 15.2 cm by 15.2 cm (6.0 in. by 6.0 in.) panel-mounted display, viewed from a distance of 78.7 cm (31 in.).

In general, the displays used to exemplify different concepts, symbolologies, and formats contained more information than would be incorporated into a cockpit panel display. This was done because it was felt that pilots could more easily judge whether a particular display element should be included in a CDTI, or how it should be presented, if they had actually seen it than if they had to guess what a particular feature would look like if it had been added. The displays that were created served as a series of "straw men" for which the pilots were encouraged to suggest additions, substitutions, and deletions. The pilots were never asked to select a single display combination over all of the others because they were not shown all possible combinations of elements. Rather, the pilots were asked to evaluate each element individually and in contrast to others for concept and format.

In the following sections, the questions that were asked and the displays that were used as examples are summarized, for each category of information that was included, in the order that they were presented to each group of pilots. In addition, photographs of representative displays are included.

Map scale- Six different map scales were simulated to familiarize pilots with the varying display content that they might encounter on a descent from 15,000 ft to the outer marker. (Note that "miles" refers to nautical miles in this report.) The areas covered by the six map scales were 4 miles (fig. 1); 8, 16, and 32 miles (fig. 2); and 64 and 128 miles (fig. 3) from top to bottom and from side to side.

Because the displays in this study were static, map scaling (e.g., continuous or discretely stepped) per se was not a variable; however, the amount and type of information that pilots wanted displayed at different altitudes and during different phases of flight were examined.

Map orientation- All of the maps were presented with a heading-up orientation. Although a north-up orientation has the advantage of being visually stable (ref. 6) and is useful for planning purposes (ref. 7), a heading-up orientation may be more appropriate for control because the direction of flight and control is obvious and control reversals are less of a problem.

Navigation display- Because a CDTI could perform multiple functions, consideration was given to providing a graphic display of routes, navigation aids, airports, and intersections to assist the pilot in placing the position of his own and other aircraft in context and for use in primary navigation. The variables investigated included: (1) Which routes should be displayed - own route only, own and intersection routes, or all routes within the range of the map? (2) What symbology should be used for navaids, intersections,

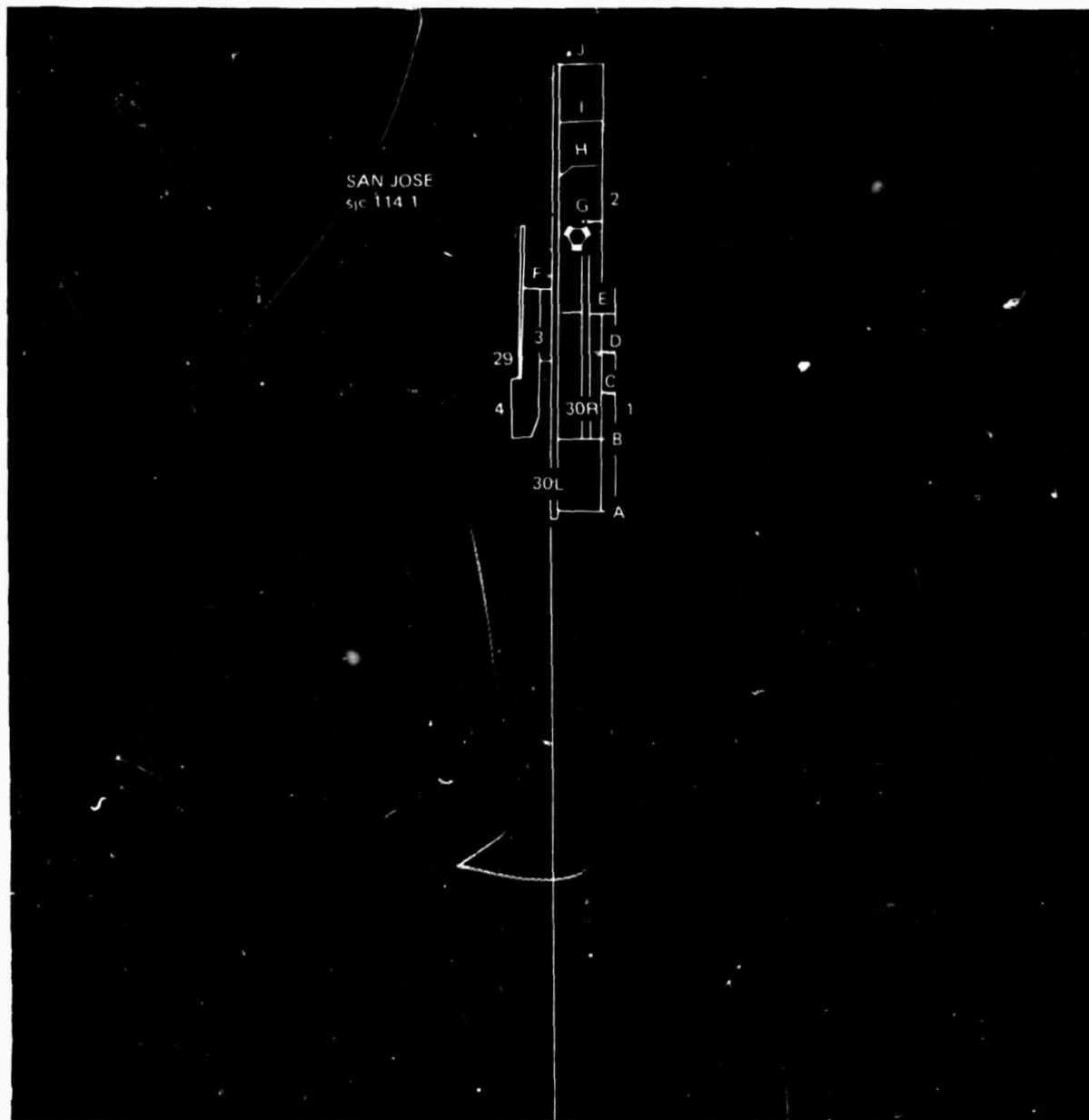


Figure 1.- Navigation display for southern approach to San Jose Municipal Airport: 4 miles full scale.

and airports? (3) Should intersections, nav aids, airports, and routes be labeled? and (4) How should current map scale and map orientation be presented?

A limited set of commonly charted symbols was used to denote intersections, VORTAC/VORDME, and outer markers. For larger map scales, all

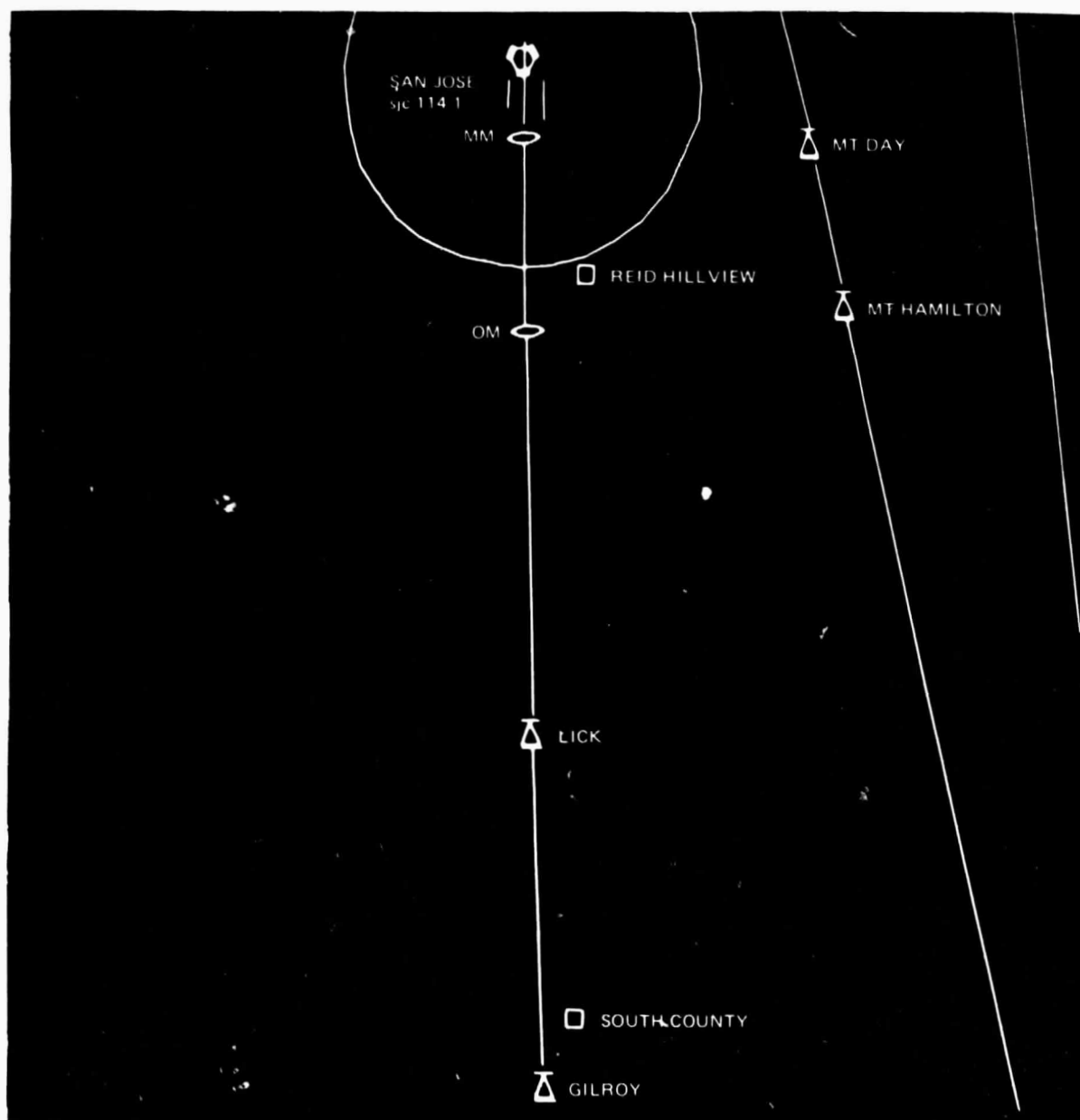


Figure 2.- Navigation display for southern approach to San Jose Municipal Airport: 32 miles full scale.

airports were represented by a square symbol and those with a colocated VORTAC/VORDME were represented by a combined symbol (fig. 4). For the 4-, 8-, 16-, and 32-mile map scales, the runway structure of the destination airport was shown instead of a square symbol. The taxiways were shown as well on the 4-mile scale (fig. 1). The airport control zone was displayed on the 8-, 16-, and 32-mile scales. All low-altitude enroute airways

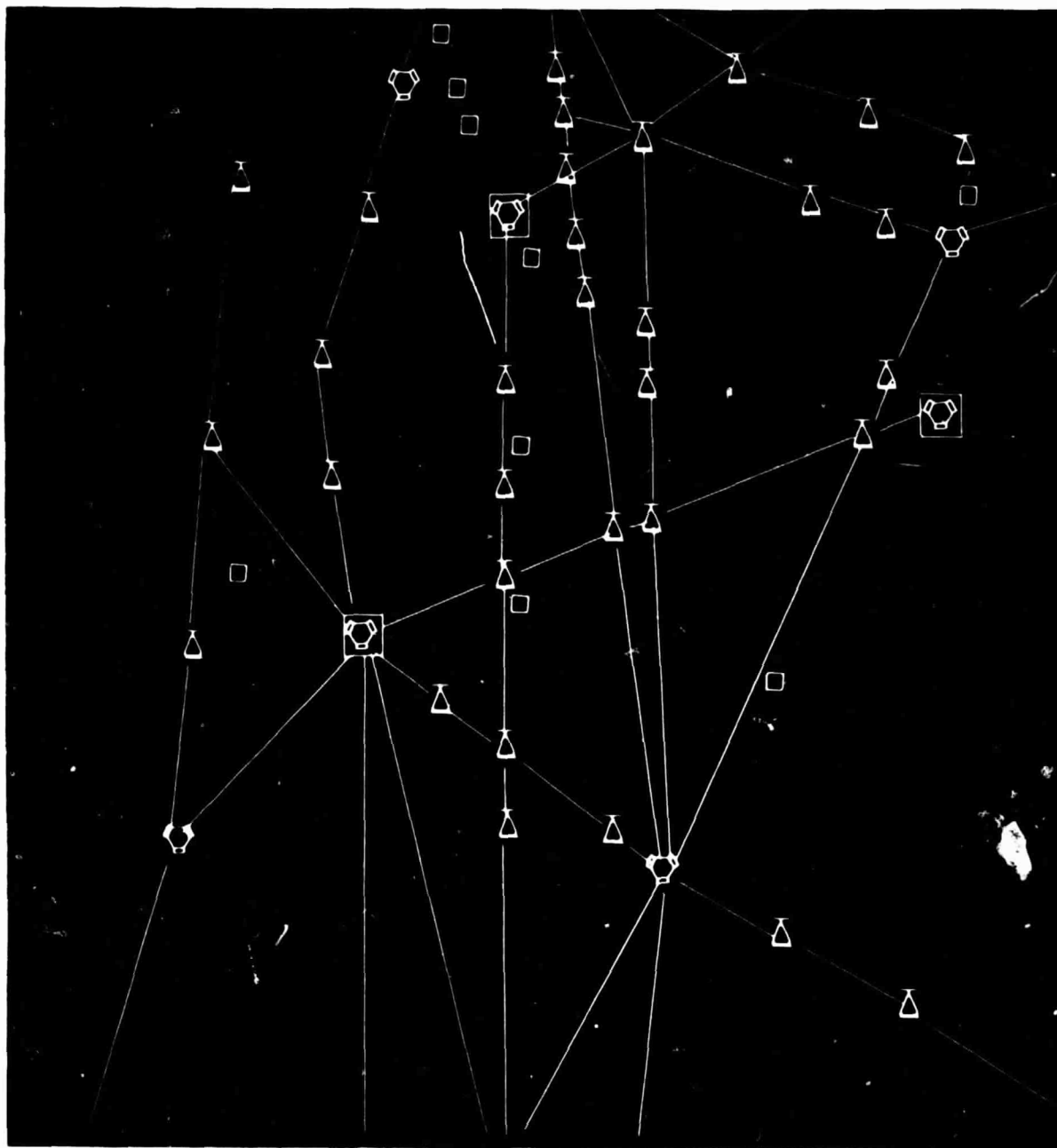


Figure 3. - Navigation display for southern approach to San Jose Municipal Airport: 128 miles full scale.

within the range of each map were displayed. In addition, all intersections, nav aids, and airports within the range of each map were shown symbolically, with and without identifying labels. Different ways to display map scale values and current map orientation digitally were investigated. The pilots were asked to evaluate 29 different attributes of the navigation display.

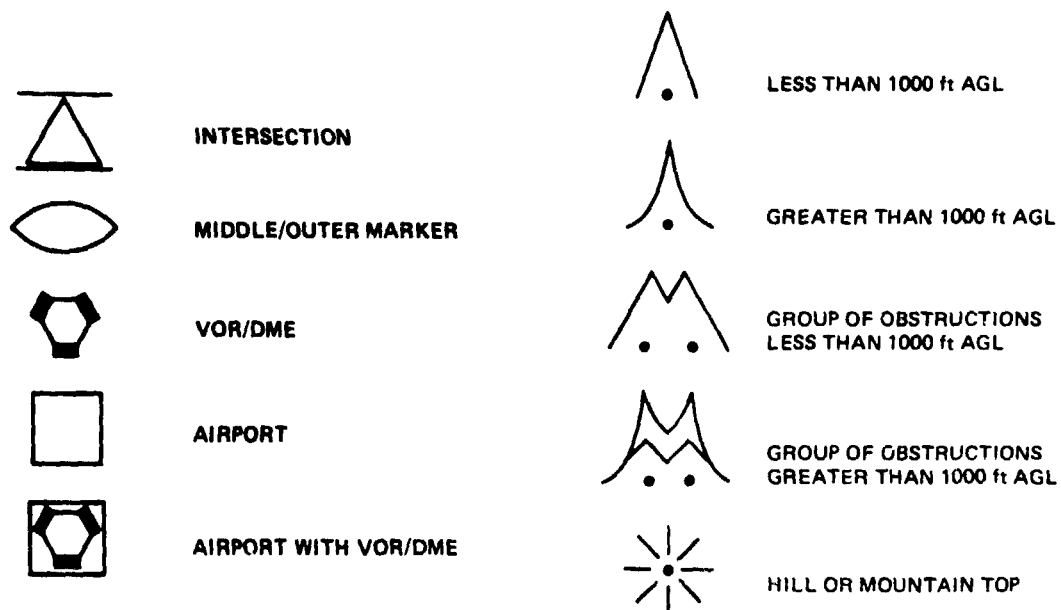


Figure 4.- Proposed navigation symbology.

Figure 5.- Proposed terrain symbology.

Terrain display- Several different ways to display terrain information on a CDTI were presented. The questions investigated included: (1) Should terrain be displayed on the CDTI? (2) Should it be displayed at pilot request or automatically if there is a threat? (3) What obstructions should be displayed? (4) How should they be displayed? and (5) Should terrain information be differentiated by shape-coding of symbols and/or color coding?

All significant natural and manmade obstructions that were within 5,000 vertical ft of the simulated altitude of own aircraft and the range of the map were graphically superimposed on each of the maps as an additional feature. Five frequently used chart symbols were proposed (fig. 5) although not all were used. The height of each obstacle was labeled in feet beside the symbol. The symbols were shown to the pilots, individually and in combination with other information. Figure 6 depicts a terrain display superimposed on a 32-mile map.

In addition, a ground-referenced grid was superimposed on each map with the minimum safe altitude within each section presented in hundreds of feet as an alternative or addition to the display of specific terrain features. Different grid sizes were used for different scales: 2-mile grids for the 4-, 8-, and 16-mile maps; 5-mile grids for the 32-mile map; and 10-mile grids for the 64- and 128-mile maps. The ground-referenced grid surrounding the pilot's own aircraft as well as adjacent areas ahead and to the side were

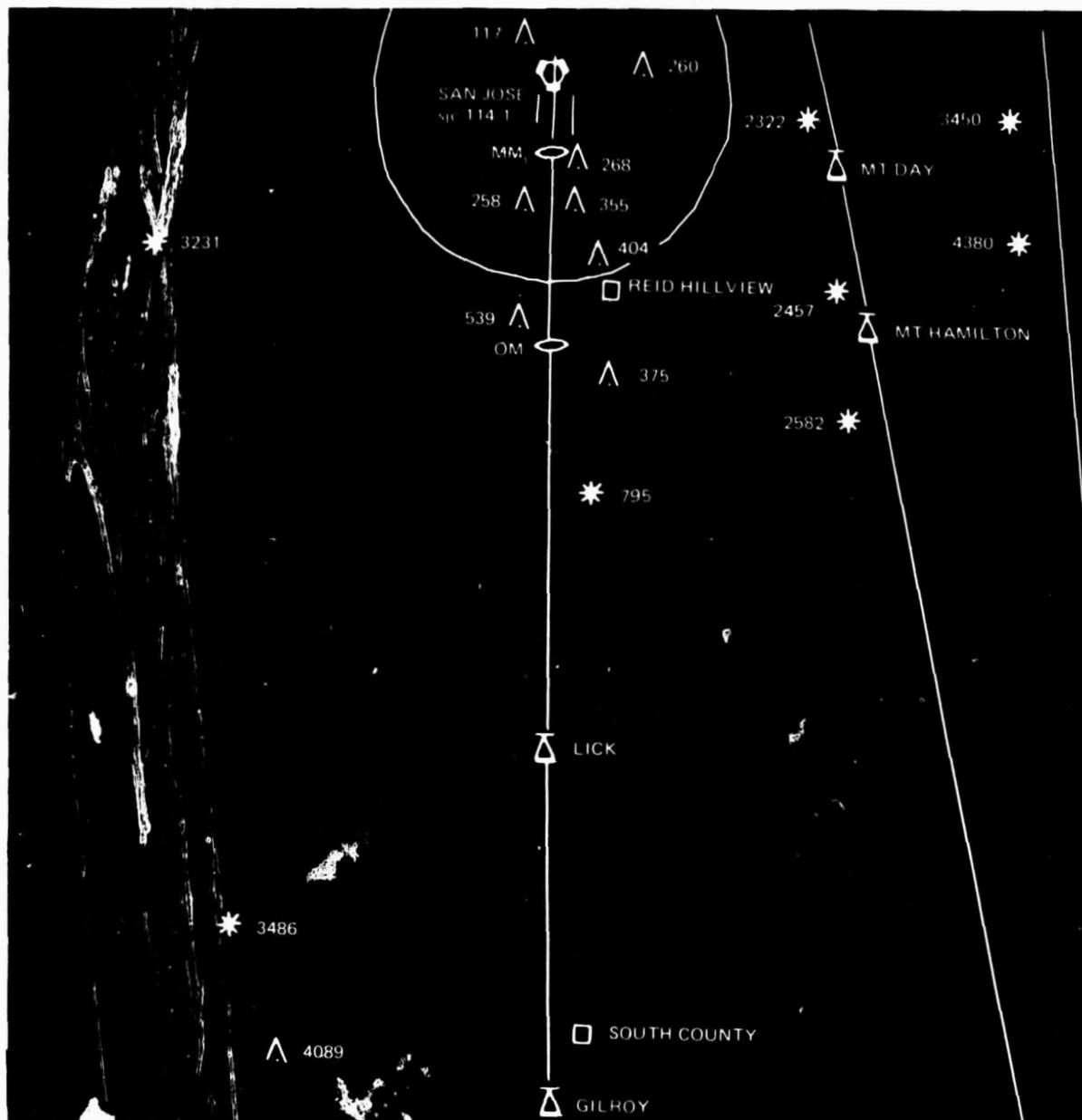


Figure 6.- Terrain symbology superimposed on a 32-mile map representing a southern approach to San Jose Municipal Airport.

displayed (fig. 7). In concept, the grid display is similar to the minimum safe altitude warning (MSAW) data base currently in use by ATC with which controllers automatically receive a warning when an aircraft is in immediate jeopardy or when it is predicted that it will be within 30 sec. The pilots were asked to respond to 32 items related to the display of terrain.

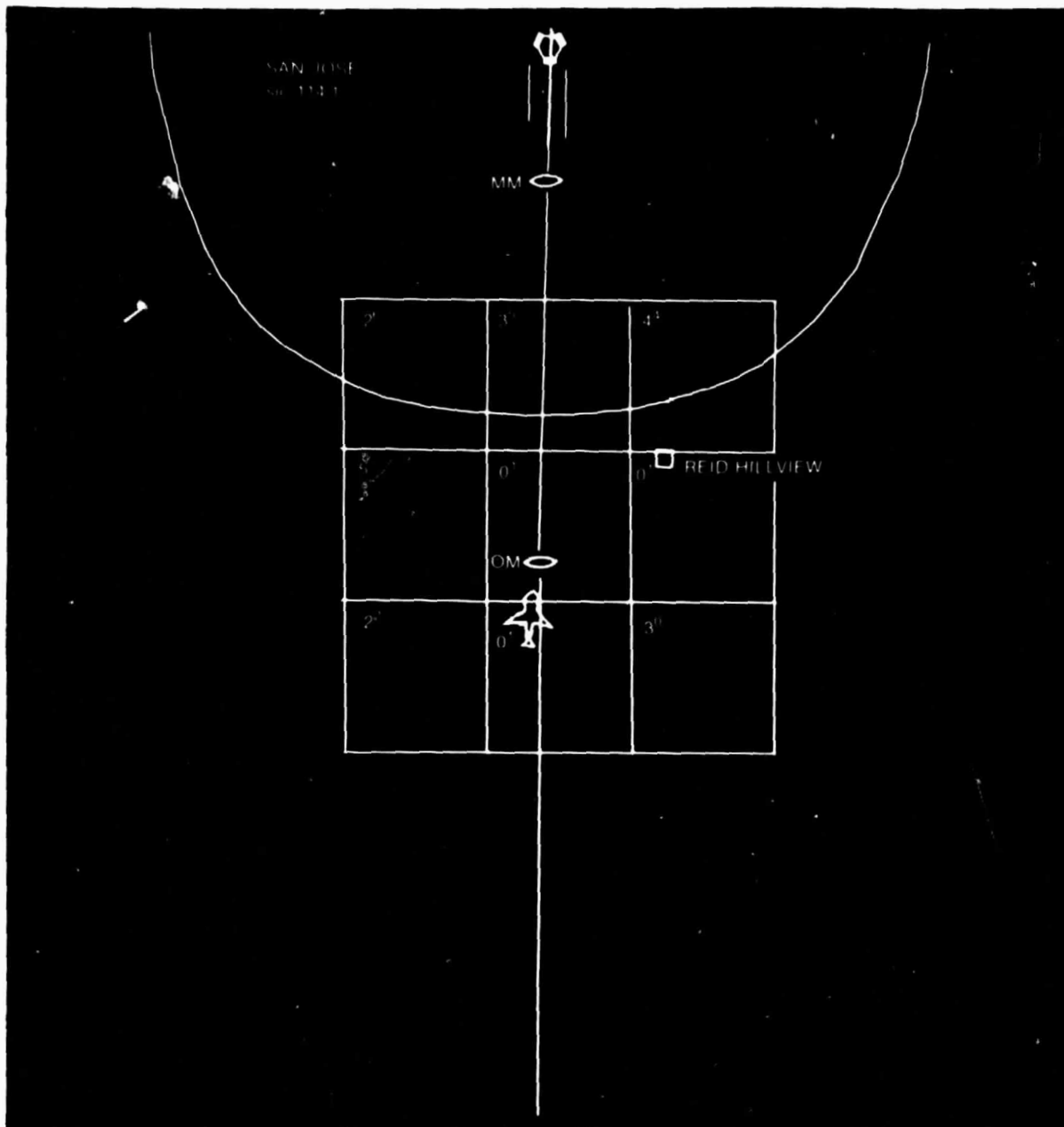


Figure 7.- Five-mile square grids that depict the minimum safe altitude in each section in hundreds of feet (superimposed on a 16-mile map).

Weather display- A CDTI could include a graphic display of weather as well as other types of information. The questions studied with respect to providing such an option included: (1) Should weather be displayed on the CDTI at all? (2) Should a weather display appear at pilot request and/or automatically? (3) What information about weather should be displayed? and (4) How should information about weather be displayed?

The pilots were shown three candidate displays depicting weather only and weather in combination with other types of information. One display depicted the location of the weather by radial lines emanating from a radar site, with a letter indicating areas of intensity. In this study, different letters were used to indicate the nature of the weather (e.g., "A" for hail and "R" for rain). A second alternative displayed the letters only to indicate the location and nature of heavy precipitation. A third alternative was shown in which a dot pattern was superimposed on the map to show location of weather only, with no indication of intensity or nature (fig. 8). The color-coded

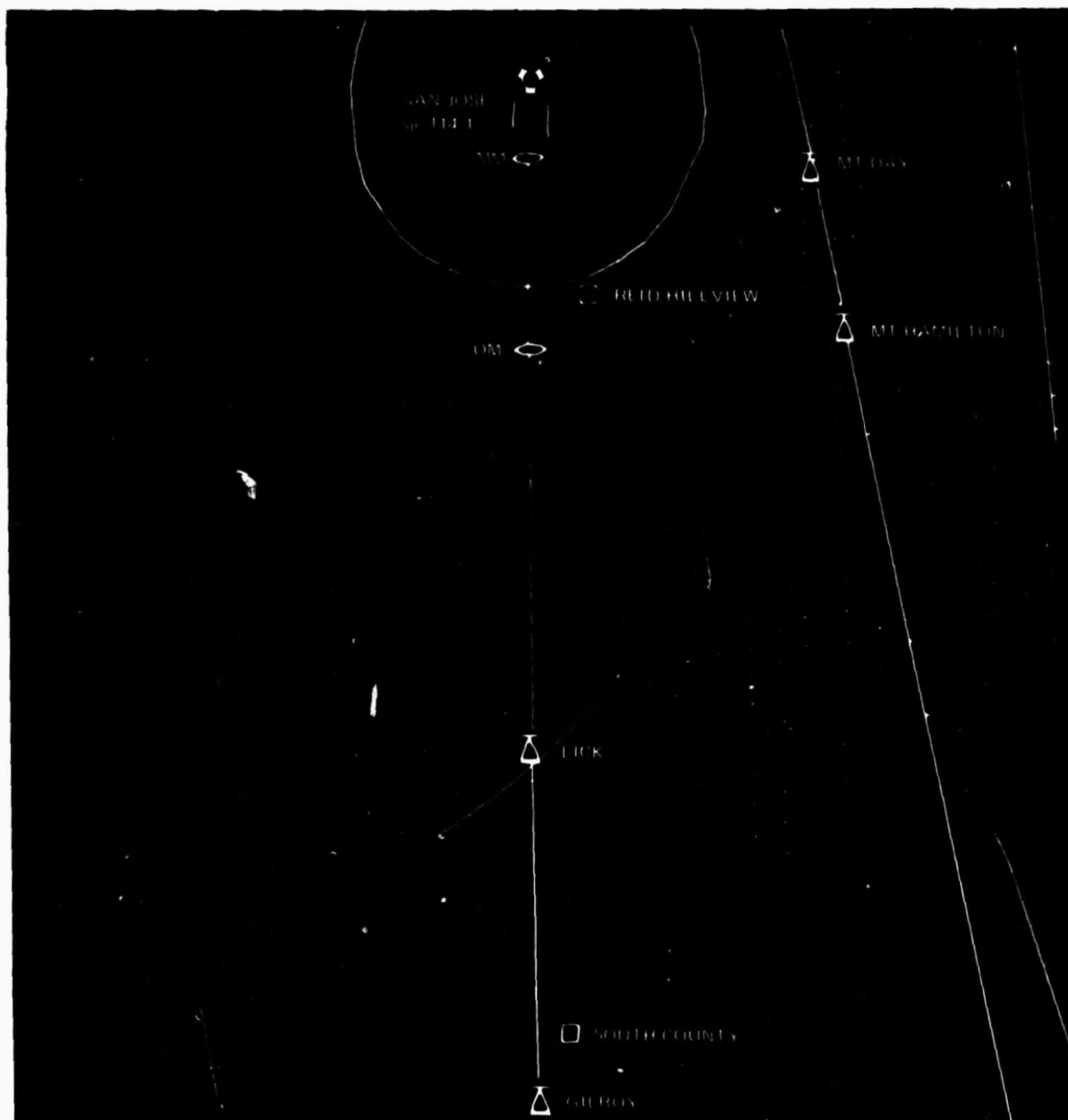


Figure 8.- Example of graphic display of the location of weather superimposed on a 32-mile map.

digital weather displays that are commercially available were not simulated, although the pilots were free to select that as an option instead of the three that they were shown. The pilots were asked to respond to 13 different questions related to a display of weather.

Own aircraft display- Different ways of representing a pilot's own aircraft were investigated with particular emphasis on: (1) symbology; (2) location of the symbol on the display; and (3) the relationship between the representation for own and other aircraft. The pilots were told that the location of the symbol representing their own aircraft would be fixed and that the map would rotate in a heading or track-up orientation mode.

Six symbols, including most of the symbols that are in current use, were shown to the pilots on a single display with and without flight path predictors (fig. 9). In addition, each of the symbols was shown to the pilots in

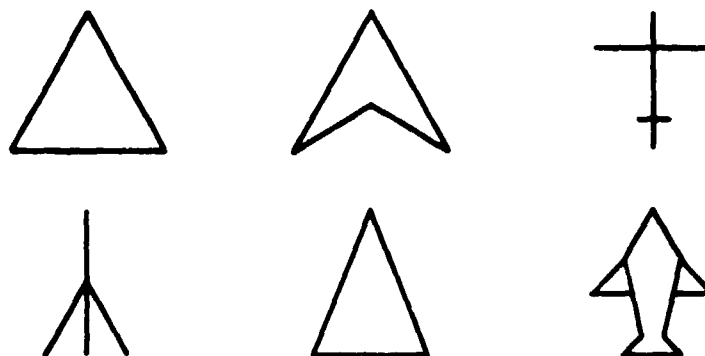


Figure 9.- Candidate symbols for own aircraft.

the context of a basic navigation display. Three possible vertical locations for the own aircraft symbol were shown for a track-up map orientation (it was always centered laterally): (1) centered; (2) offset so that 2/3 of the map was ahead; and (3) offset so that 3/4 of the map was ahead. In addition, the pilots were asked whether the symbols for own and other aircraft should be differentiated by symbol shape, size, or color, or by some combination. Forty-three different questions were asked regarding own aircraft symbology and location.

Traffic display- Since the primary function of a CDTI will be to provide a graphic display of adjacent traffic, a major effort was made to determine: (1) What other aircraft should be displayed? (2) What symbology should be used? (3) What information about the status of other aircraft should be displayed in addition to position? and (4) How should it be presented? Nearly half of the questions that the pilots were asked were related to displaying the position and status of other aircraft.

Rules for displaying other aircraft- If all aircraft within the range of the map were displayed, a CDTI might become too cluttered. Rules were investigated by which the proportion of aircraft shown would be limited to those that are relevant. The logic for determining which other aircraft should be displayed could be related to own aircraft altitude, speed, or map scale, or to some combination. Displayed traffic could also be limited to those on the pilot's own route and intersecting routes or those within a specific lateral distance. Several rules for displaying other aircraft were described to the pilots and representative displays were shown.

Symbology for other aircraft- The simplest representation of another aircraft would be a nondirectional symbol that depicts position only. A nondirectional symbol could be a square, diamond, pound sign, pentagon, or octagon. In this study, the concept of a nondirectional symbol was represented by a circle. The symbol could also include information about direction of flight. A track line could be added to a nondirectional symbol, or the symbol's orientation could depict the aircraft's direction of flight (e.g., a directional symbol). In this study, an isosceles triangle and a track line added to the circular, nondirectional symbol were suggested as two ways to display direction of flight. In addition, a flightpath history or "trail" was provided to display several previous positions of other aircraft. This also provided an indication of direction of flight by extrapolation.

Each of the five basic symbols (fig. 10) was used as the symbol for other aircraft on a 32-mile traffic situation display that represented a traffic

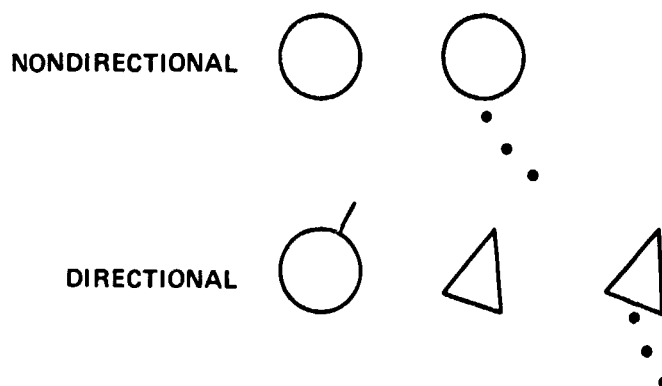


Figure 10.- Representative directional and nondirectional symbols for other aircraft with and without flightpath history.

density typical of the San Jose area, with altitudes within $\pm 4,000$ ft of the pilot's own altitude (fig. 11). The same positions, altitudes, and densities were used for each of the displays. The pilots were asked to rate each of the five basic symbols for visibility and the ease with which they could determine the intent of an aircraft depicted by that symbol.

Coding of symbols for other aircraft- The shape of the symbol used to depict the position of other aircraft could also be varied to display

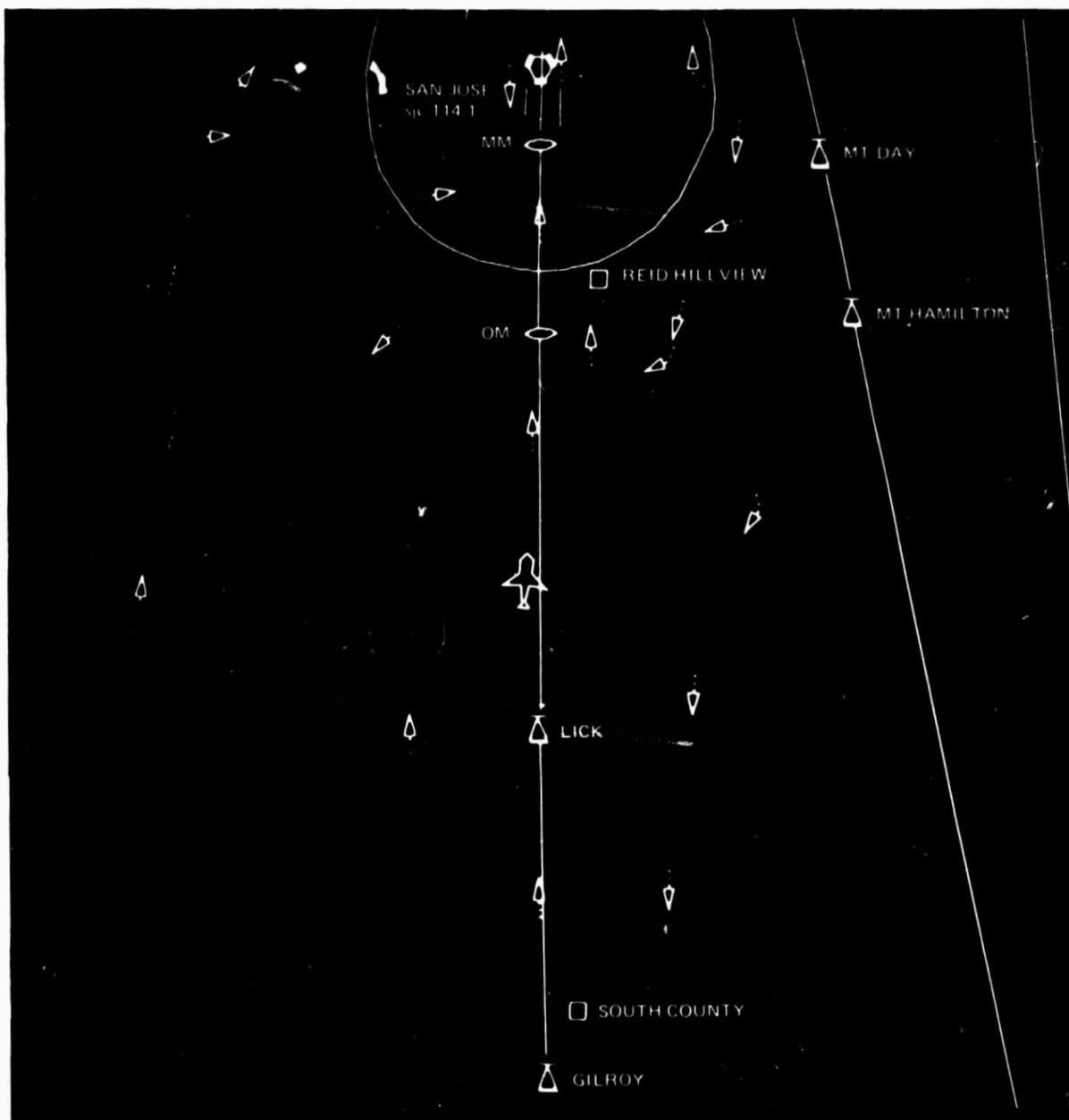


Figure 11.- Traffic display superimposed on a 32-mile map: directional symbols with flightpath history.

additional status information graphically. Examples of eight coding schemes were shown in which the shapes of the symbols were varied to depict ATC status alone (fig. 12) or ATC status and CDTI equipage (figs. 13 and 14) and the relative altitude of the aircraft with respect to the altitude of a pilot's own aircraft (figs. 15 and 16). Two relative altitude encoding concepts were shown: (1) the nondirectional symbols differentially indicated whether an aircraft was above, at, or below the altitude of a pilot's own altitude; and (2) the directional symbol showed whether another aircraft was at the same altitude as the pilot's own aircraft, but did not differentiate between aircraft that were above or below. Three coding schemes combined information

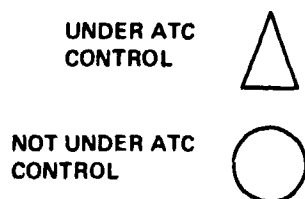


Figure 12.- Examples of symbols coded to depict whether an aircraft is under ATC control.

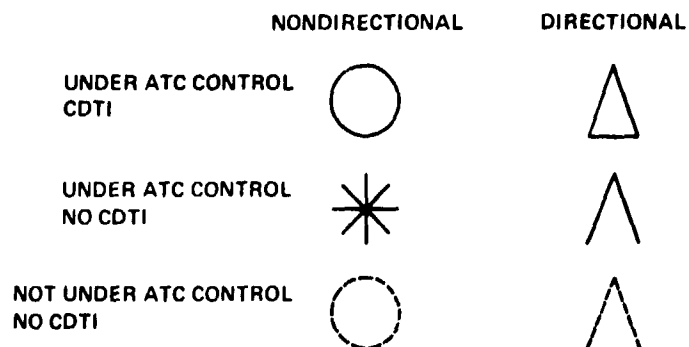


Figure 13.- Examples of symbols coded to depict whether an aircraft is under ATC control and is CDTI-equipped.

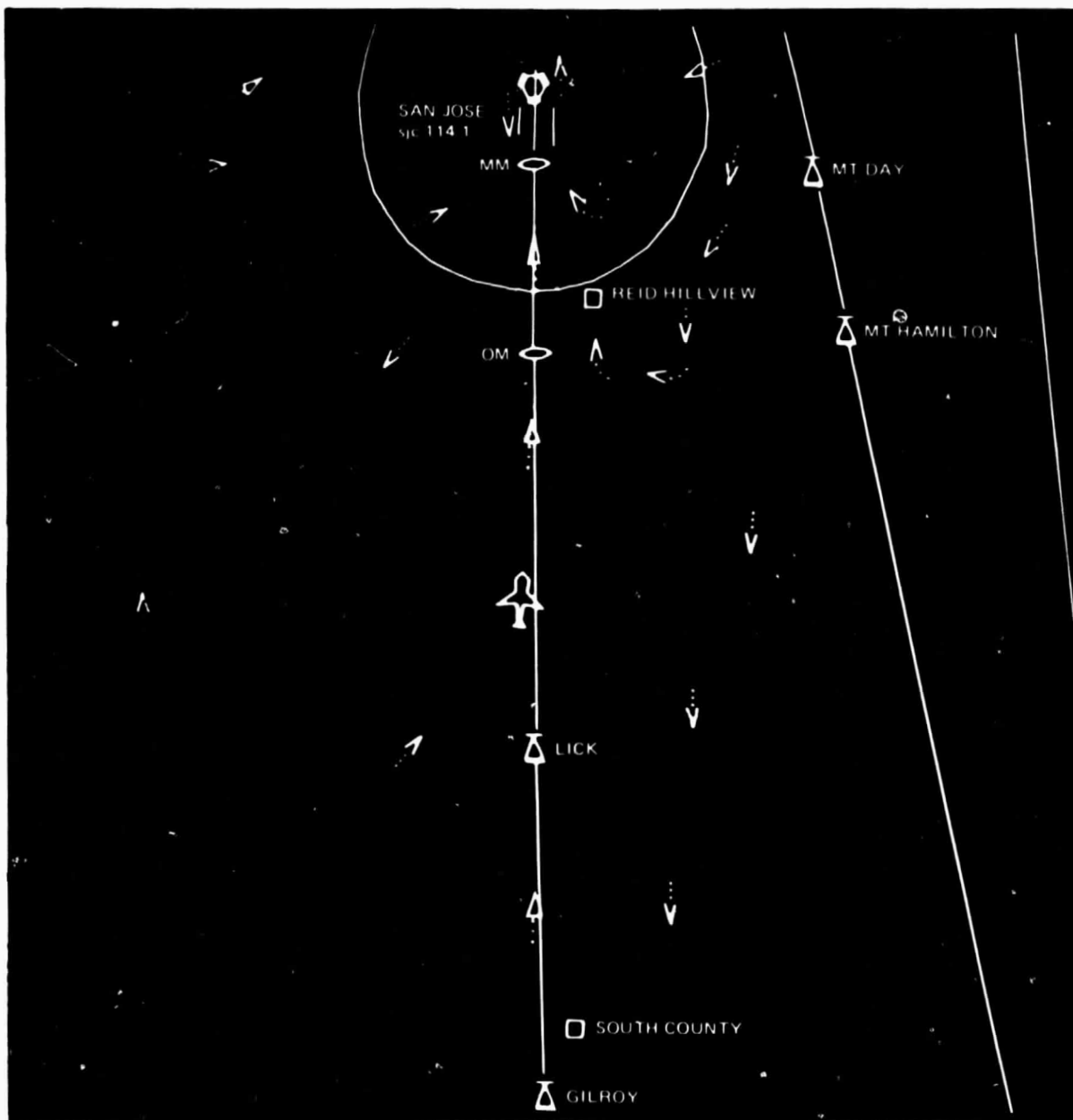


Figure 14.- Traffic display superimposed on a 32-mile map: directional symbols with flightpath history coded to depict ATC control and CDTI equipment.

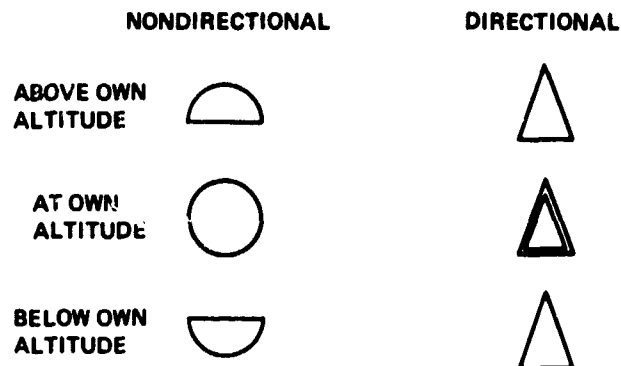


Figure 15.- Example of directional and nondirectional symbols coded to depict the relative altitude of another aircraft.

about relative altitude with presence or absence of ATC control (fig. 17) and CDTI equipage (figs. 18-20).

After the pilots were familiarized with the coding schemes, each of the different coding concepts and symbologies was presented, with and without flightpath histories and track lines, in the context of 32- and 128-mile maps. The pilots were asked to evaluate each of the combinations of basic symbol shapes (directional or nondirectional) with and without flightpath histories and status encoding (relative altitude, ATC status, and CDTI equipage) for concept and symbology and to select the one that they preferred.

Additional status information- The pilots were asked to specify what additional information they might need to know about the status of other aircraft. They were given a list of 18 items (table 1) and were asked to indicate whether they felt each individual item was: (1) necessary; (2) desirable but not necessary; (3) not needed; or (4) not wanted.



Figure 16.- Traffic display superimposed on a 32-mile map: directional symbols with flightpath history coded to depict the relative altitude of another aircraft.

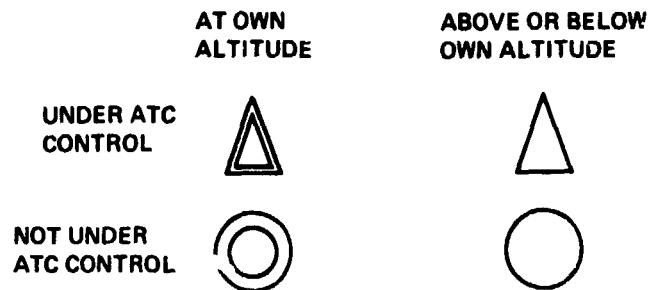


Figure 17.- Example of symbols coded to depict relative altitude and ATC control status of another aircraft.

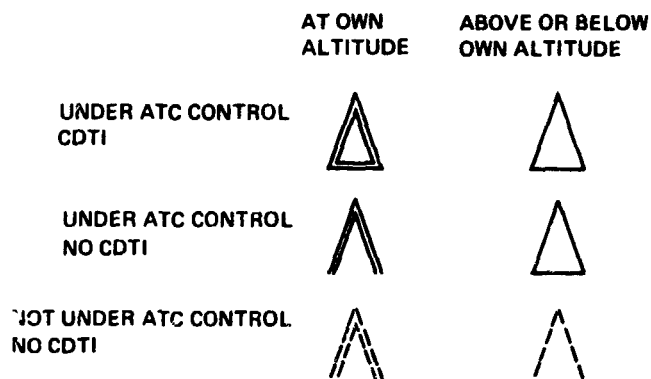


Figure 18.- Example of directional symbols coded to depict the relative altitude, ATC status, and CDTI equipment of another aircraft.

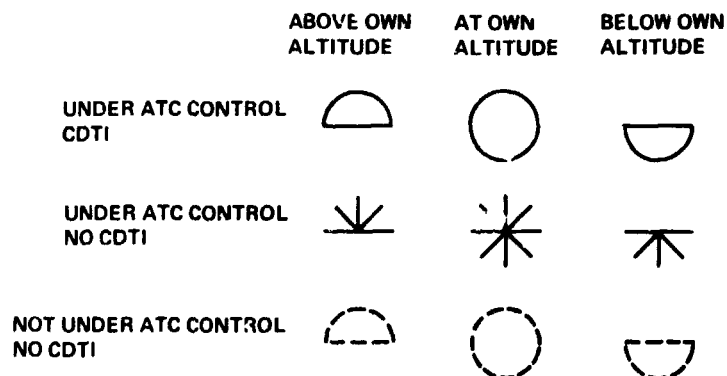


Figure 19.- Example of nondirectional symbols coded to depict the relative altitude, ATC status, and CDTI equipment of another aircraft.

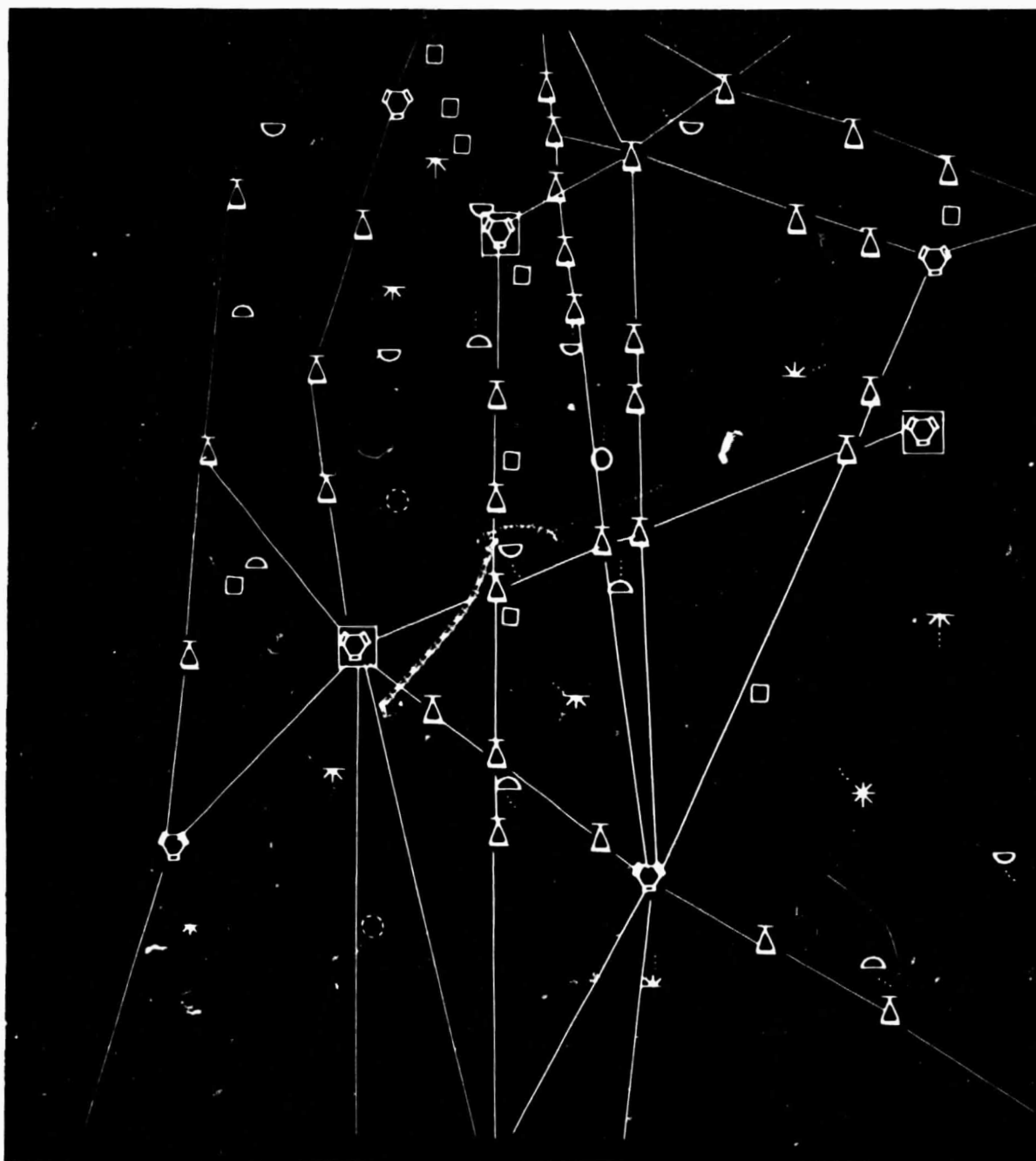


Figure 20.- Traffic display superimposed on a 128-mile map: nondirectional symbols with flightpath history coded to depict the relative altitude, ATC status, and CDTI equipage of another aircraft.

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TABLE 1.- INFORMATION ABOUT THE STATUS OF OTHER AIRCRAFT
THAT COULD BE DISPLAYED ON A CDTI

1. Identification	10. Ground track
2. Weight class	11. Heading
3. Aircraft type	12. Destination airport
4. Altitude	13. Assigned runway
5. Assigned altitude	14. Sequence number for landing
6. Relative altitude	15. Flightpath history
7. Vertical speed	16. ATC status
8. Climbing or descending	17. CDTI onboard or not
9. Ground speed	18. Emergency status

They were then asked to select a preferred display format for the different types of status information: (1) symbol encoding (by shape or color); (2) digital data blocks; (3) digital data blocks displayed at pilot request only; and (4) an alphanumeric table on an additional display. They were asked also to rate different data block formats and to select a method for requesting a data block display. Figure 21 depicts a traffic situation display superimposed on a 16-mile map in which data blocks are displayed beside each aircraft.

Monochromatic vs multicolor displays- The final phase of this study involved simultaneous presentation of a cross section of the displays shown monochromatically (green only) and with color coding (green for navigation, yellow for terrain and weather, and red for digital and symbolic information about own and other aircraft) to determine, in the pilot's opinion, whether color coding was necessary for speed and accuracy of recognition, to evaluate the intent and position of other aircraft, to maintain separation, and for merging. Further, they were asked whether they preferred that different categories of information be differentiated from each other by color coding, symbol configuration, or printed labels.

Concluding questions- At the conclusion of the study, the pilots were asked their opinions about several display features that they had not been shown (e.g., map scaling and display size). In addition, they were asked to estimate the effect a CDTI might have on their workload and whether they felt that a CDTI would provide them with useful information about the position and intention of other aircraft.

RESULTS

Statistical Procedure

The responses to each of the questions were summarized for each subject group individually and then combined across groups. No significant group effect was found for any of the questions. The significance of the pilots'

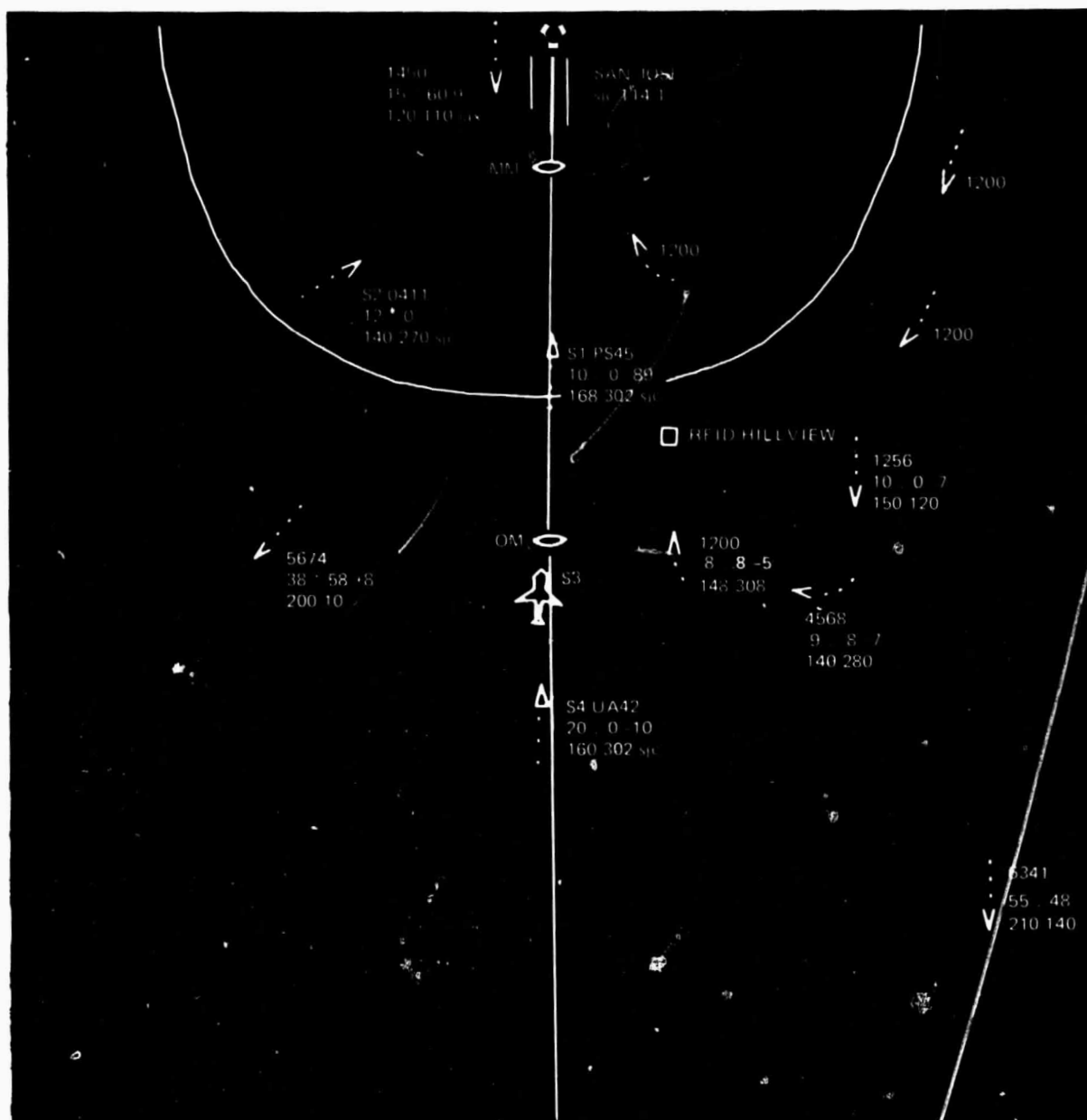


Figure 21.- Traffic display superimposed on a 16-mile map: data blocks are provided that present available information about the i.d., sequence number for landing, altitude, direction of vertical change, assigned altitude, ground speed, heading, and destination airport of other aircraft.

responses was computed in the following way: (1) because the responses were discrete in nature and the expected cell values of the alternatives were small, the multinomial distribution was used to determine a test for statistical significance; (2) with the assumption that the alternative choices allowed for each question were equally likely to be chosen by each of the 23 subjects, the probability that the favored one (or more) of the alternatives would be chosen R or more times by chance alone was computed; and (3) the value of R when $p = 0.05$ was used as the critical value for the 95%(*) level of confidence that a significant preference was indicated by the data. A similar value of R was determined for the 99%(**) level of confidence (table 2).

TABLE 2 - CRITICAL VALUES (MINIMUM NUMBER AND PERCENT OF SUBJECTS SELECTING A SPECIFIC ALTERNATIVE) REQUIRED TO ASSERT THAT A SIGNIFICANT PREFERENCE WAS EVIDENT IN THE RESPONSES OF THE 23 SUBJECTS

Number of alternative responses possible	Level of confidence			
	95%		99%	
	Number of subjects choosing one of the alternatives	Percent of subjects choosing one of the alternatives	Number of subjects choosing one of the alternatives	Percent of subjects choosing one of the alternatives
2	17	74	18	78
3	14	61	15	65
4	12	52	13	56
5	10	43	11	48
6	9	39	10	43
7	9	39	10	43
8	8	35	9	39

Navigation Display

Symbolology- A significant number of pilots (between 83 and 100%) considered each of the proposed symbols (fig. 4) to be acceptable. In addition, several pilots suggested that their own route and the symbol for the destination airport should be distinctive.

Graphic display of airport control zone- Although 64% of the pilots wanted the airport control zone (i.e., a circle around the airport with a 5-mile radius) to be displayed graphically on the 8- and 16-mile maps, less than 25% of them wanted it displayed for any other map scale.

Route structure- Fifty-seven percent of the pilots wanted their own route to be the only one displayed for the 4- and 8-mile maps (fig. 22). For intermediate map scales, 52% of the pilots wanted intersecting routes as well as their own displayed. For the 64- and 128-mile maps, 45% wanted their own and intersecting routes displayed, and 52% wanted all of the routes within the range of the map displayed.

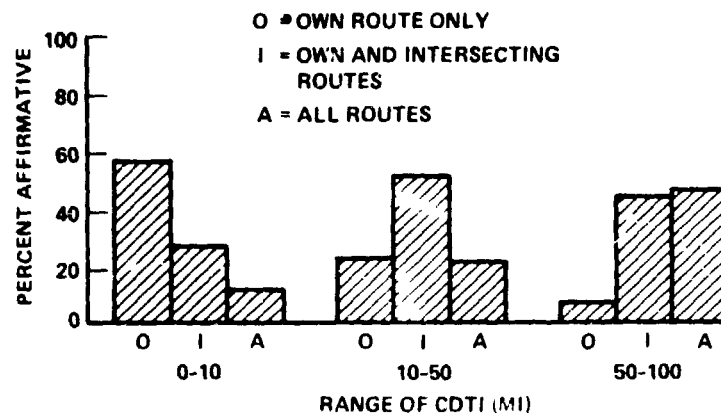


Figure 22.- Proportion of routes within map range to display for different map scale.

Labels- A significant number of pilots (75 to 90%) wanted intersections, airports, and nav aids to be identified at intermediate map scales. Less than 50% of them felt that labels were necessary for the 4-, 64-, and 128-mile maps.

Taxiways- One-third of the pilots felt that taxiways should be displayed on the 4-mile map. The remaining pilots felt that taxiways should be displayed only after the aircraft landed or not at all.

Digital display of heading/ground track- One-third of the pilots preferred a digital display of their own aircraft heading, 48% preferred a digital display of their own ground track, and 17% selected both.

Digital display of map scale- One-third of the pilots preferred a digital display of the total number of miles covered by the map, 52% selected the alternative of displaying the number of miles to the top of the map, and 16% wanted both. Several pilots commented that they would prefer a grid or range rings for mileage reference displayed on the map at pilot request.

In addition to the options that the pilots were shown and the alternative responses that were provided, three or more pilots suggested the following options: (1) show air carrier airports only; (2) provide the pilot with the option of canceling the display of small airports, secondary intersections, and nav aids; (3) provide labels on own route only; (4) allow pilots the option of selecting the number of routes in addition to their own to be displayed; and (5) display primary holding patterns and missed approach routes at pilot request.

Terrain Display

A significant number of pilots (91%) felt that a terrain display should be incorporated into a CDTI. All of the pilots wanted the display to appear automatically if their aircraft had descended below the minimum safe altitude, and 77% felt the terrain display should appear at pilot request as an additional option.

Symbology- Although more than half of the pilots found the terrain symbols that were used (fig. 5) to be acceptable, a significant number of them thought that only two symbols were necessary: one symbol for manmade obstructions and one for natural obstructions. They reported preferring the first and last symbols shown in figure 5 if only two symbols were used to depict terrain.

Rules for displaying terrain- All of the pilots reported that the terrain features displayed should be related to their own aircrafts' altitude. In addition, many pilots felt that the proportion of terrain features displayed should vary with map scale and/or with own aircraft speed as well. More than half of the pilots thought that obstacles less than 1,000 or 2,000 ft below their own aircraft should be the only ones displayed (fig. 23).

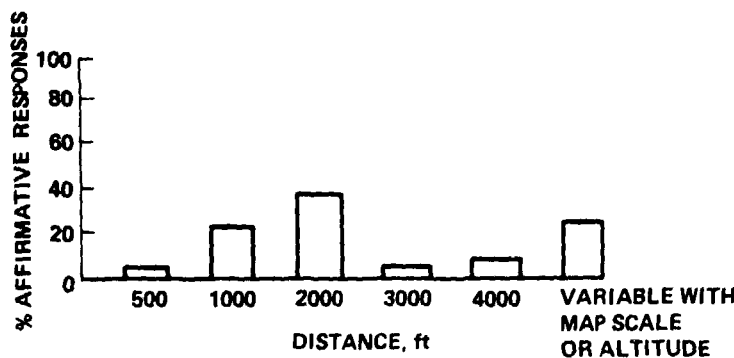


Figure 23.- Maximum distance of obstructions beneath own aircraft that should be included in a terrain display on a CDTI.

One-fourth of the pilots felt, however, that the algorithm for displaying obstacles should vary with altitude (i.e., the closer the aircraft is to the ground, the closer the obstacle should be to the aircraft before it is displayed on the CDTI).

Several pilots suggested that only those obstacles that are directly in the path of their own aircraft should be displayed. Others suggested that terrain symbol size should vary with the height of the obstruction and that colors should be used to provide a relief-type representation of mountain ridges.

Grid displaying minimum safe altitudes- More than half of the pilots felt that a grid with the minimum safe altitude for each section, displayed in hundreds of feet, would be an acceptable alternative to displaying specific obstacles. All but one of the pilots felt that the grid should appear automatically as a warning and at pilot request as an additional option. At least 80% found the suggested grid dimensions to be acceptable, and 74% wanted the minimum safe altitude for adjacent areas in front of and beside their own position to be displayed in addition to that for their present location.

Weather Display

A number of pilots felt that weather should be indicated by an advisory message on the CDTI but that the weather display itself should be on a separate instrument. If weather is to be displayed on the CDTI, all but one of the pilots felt that it should be at pilot request or pilot-cancelable.

Symbology- Of the three types of weather displays shown, half of the pilots preferred the display that indicated location only, and one-third preferred the display that depicted location, intensity, and nature of the weather. A number of pilots commented that they preferred the digital weather radar displays currently in use and would rather have one of them as a separate weather display.

Information to display- All of the pilots felt that a weather display should at least depict the location of the weather. In addition, 87% felt that the display should indicate the intensity of the weather as well, and 61% felt that the display should also inform the pilot about the nature of the weather. This implies that the pilots wanted the information to be displayed but in a format different from that used in this survey. The format of the weather display should not vary with altitude or map scale, but different levels of detail and complexity should be available at pilot request.

Own Aircraft Display

Symbology- At least 50% of the pilots felt that each of the six symbols suggested for own aircraft (fig. 9) were acceptable for navigation, viewing ease, and for the task of maintaining separation (fig. 24(a)). Several pilots commented, however, that the equilateral triangle would not be an acceptable symbol for a north-up map orientation because it would be difficult to determine their direction of flight with it. Only two of the symbols were found to be acceptable by a significant number of pilots (e.g., more than 74%). When shown in combination with a flight path predictor, rated acceptability of the symbols changed (fig. 24(b)). Stick-figure symbols were generally found to be unacceptable when combined with a 90-sec flightpath predictor. The pilots were also asked to select the one symbol that they preferred to represent their own aircraft. A significant number of them (48%) selected the chevron from the six alternatives (fig. 24(c)).

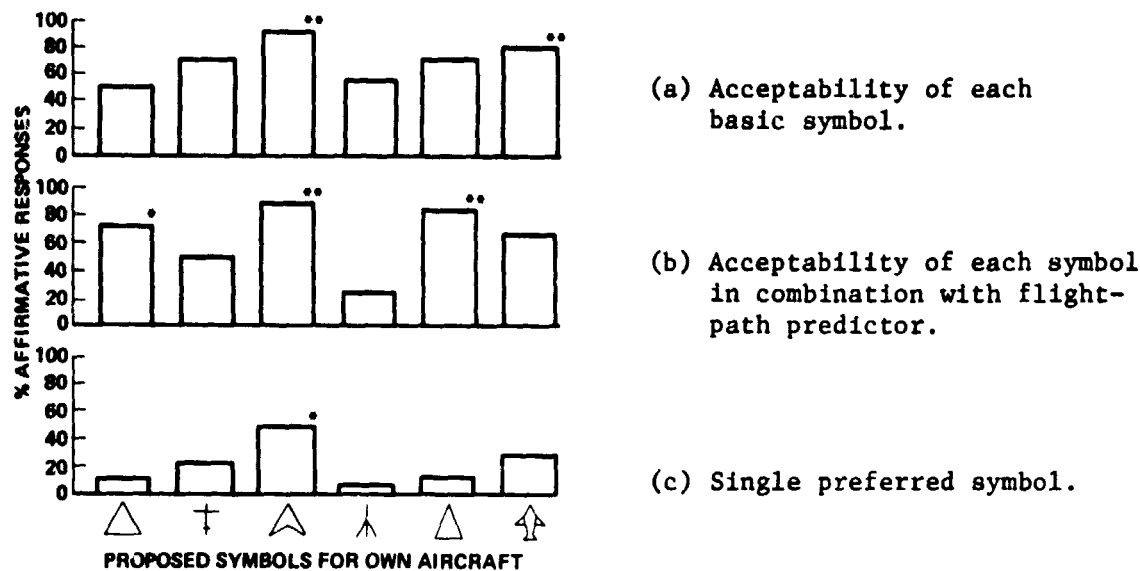


Figure 24.- Rated acceptability of symbols for other aircraft alone and in combination with a flightpath predictor and rated preference.

Location of own aircraft symbol on the map- Most of the pilots (96%) felt that the position of their own aircraft should be centered laterally and offset vertically toward the bottom of the display so that a greater percentage of the map area was ahead with a heading-up map orientation (fig. 25).

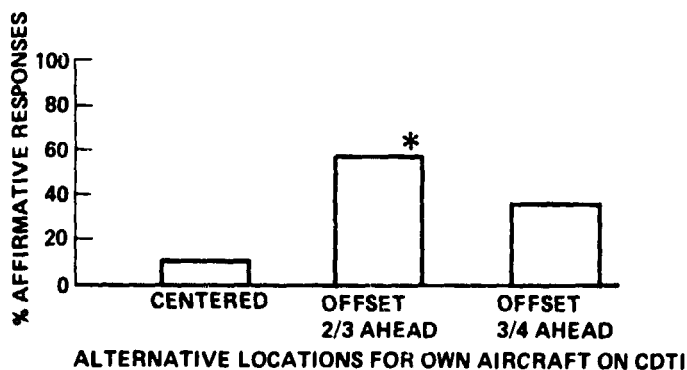


Figure 25.- Preferred location of own aircraft symbol on CDTI (heading-up or track-up orientation).

A significant number of them (61%) felt that the position of their aircraft should be offset so that two-thirds of the map was ahead. Several of the pilots pointed out, however, that the position of their own aircraft must be centered on the display with a north-up map orientation.

Relationship between symbols for own and other aircraft- A significant number of pilots reported that the symbol for their own aircraft should be larger (81%) and a different shape (96%) than the symbol(s) used for other aircraft. In addition, several pilots commented that they should be differentiated by color as well.

Traffic Display

Rules for displaying other aircraft- None of the pilots felt that all aircraft within map range should be displayed. All but one felt that the proportion of other aircraft displayed should be limited to those within a specific vertical distance of their own aircraft. Several of them also reported that the proportion of other traffic displayed should be related to the speed of their aircraft and/or the map scale. If the number of aircraft displayed was limited to a specific altitude section above and below that of their own altitude, a significant number of pilots (65%) selected a range of $\pm 2,000$ ft for fine tuning, and 43% selected the same range for merging, both of which are navigation functions (fig. 26). For routine monitoring of other aircraft, there was less agreement about the proportion of other aircraft to display: 35% of the pilots selected a range of $\pm 2,000$ ft, 13% selected $\pm 3,000$ ft, and 30% selected $\pm 4,000$ ft.

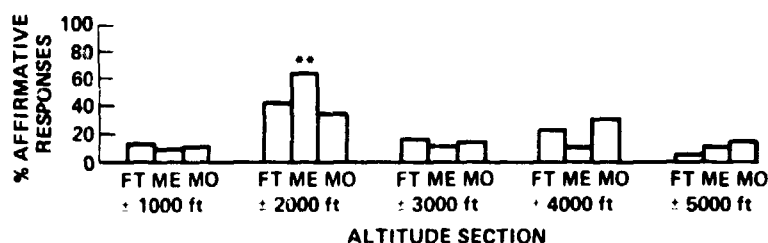


Figure 26.- Height of altitude section above and below the altitude of a pilot's own aircraft within which all traffic should be displayed; rated optimal for fine tuning (FT), merging (ME), and monitoring (MO).

Only 48% of the pilots felt that it would be appropriate to limit the display of other aircraft to those on their own and intersecting routes. This option would eliminate most general aviation aircraft from a CDTI display and, for that reason, it was not selected by many pilots. Although 74% felt that the other aircraft displayed should be limited to those within a specific lateral distance of their own aircraft, there was little agreement about what that distance should be. A number of pilots reported that they wanted aircraft at a greater lateral distance from their own position displayed when they were at higher altitudes and proportionally more of the aircraft within map range displayed at lower altitudes when the map scale would cover a smaller area.

Symbology for other aircraft- The pilots were shown five symbols for other aircraft (fig. 10) that represented four different levels of

information: (1) position only; (2) position and direction of flight; (3) position and flightpath history; and (4) position, direction of flight, and flightpath history. Only 35% of the pilots found the nondirectional symbol, presented without a ground track line or flightpath history, to be acceptably visible, and only 4% found it acceptable for determining intent (fig. 27); however, 74% found this symbol to be acceptable for determining

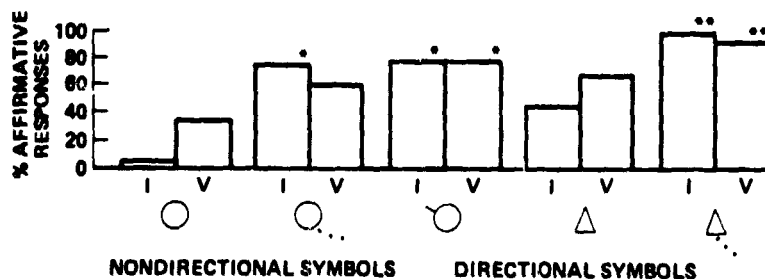


Figure 27.- Rated acceptability of the basic symbols proposed to represent other aircraft for visibility (V) and information provided about the intent of another aircraft (I).

the intent and position of other aircraft when either a flightpath history or track line is added. The directional symbol, by itself, was not found to be acceptable by a significant number of pilots; however, 83% of them rated it as acceptable for visibility and 94% rated it as acceptable for determining intent when a flightpath history was added.

Flightpath history- It was clear that the pilots thought that a flightpath history should be included in a CDTI display: 94% felt that it improved their ability to determine the position and intent of other aircraft, even though it might increase display clutter. The interval between displayed flightpath history positions should be 4 sec (48%) or 8 sec (39%).

Coding of symbols for other aircraft- The pilots were asked whether each of the coding schemes suggested (figs. 12, 13, 15, 17-19) was acceptable. At least 65% found the three coding schemes that depicted ATC status to be acceptable (fig. 28(a)). All but two of the pilots found the relative altitude encoding method used for the nondirectional symbol to be acceptable; however, fewer than half of them considered the coding scheme proposed for the directional symbol to be acceptable. A significant number of pilots (74%) felt that the multiple encoding of relative altitude, ATC control, and presence of CDTI with the nondirectional symbol was acceptable, but only 26% of them found the other two examples of multiple encoding schemes to be acceptable. When asked to select the one coding scheme that they preferred for concept and symbology, a significant number of pilots selected the nondirectional symbol - encoded for relative altitude, ATC control, and presence of CDTI - for concept (52%) and symbology (43%), even though it did not depict direction of flight (fig. 28 (b)).

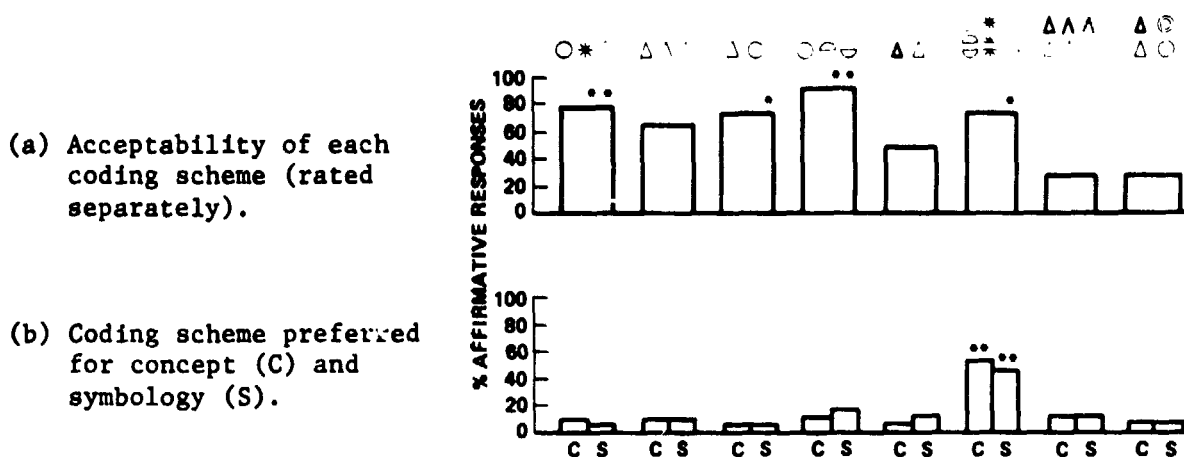


Figure 28.- Acceptability of each coding scheme that was presented and the single coding scheme preferred for concept and symbology.

Finally, the pilots were asked to select the single symbol or set of symbols that they preferred among the 24 options presented (fig. 29). A significant number (39%) selected the nondirectional symbol with flightpath history that encoded ATC status, CDTI equipment, and relative altitude. None of the pilots selected an alternative that depicted position alone. All of them selected symbols that depicted at least some additional information about the status of the other aircraft: (1) 72% selected a symbol or combination of symbols that included path history; (2) 51% selected a symbol that displayed direction of flight; (3) 82% selected symbols that encoded relative altitude (61% chose symbols that differentiated between aircraft that were at, above, or below own altitude, and 21% chose symbols that simply differentiated aircraft at own altitude from those that were not); and (4) 92% selected symbols that encoded ATC status.

It was apparent that the pilots would have preferred a directional symbol that differentiated between aircraft at, above, or below the altitude of a pilot's own aircraft. The coding scheme that was used for the directional symbols did not include all of this information and will require further development.

Additional status information- The pilots were asked to evaluate the potential value of 18 different types of information about the status of other aircraft. A significant number of pilots (74% or more) felt that it would be necessary or desirable to know: (1) altitude; (2) emergency status; (3) ATC status; (4) ground track; (5) ground speed; (6) weight class; and (7) flightpath history. In addition, 70% of the pilots wanted to know the relative altitude of other aircraft (table 3).

When asked to select the format for the different types of status information, more than 54% selected digital data tags displayed at pilot request (table 3). None of the other display options was selected by a

TABLE 3.- INFORMATION THAT PILOTS FELT THEY NEEDED TO KNOW, OR WOULD LIKE TO KNOW, ABOUT OTHER AIRCRAFT

Rank order	Information	Affirmative responses, %	Preferred source of information				
			Coded symbol, %	Permanent, %	On request, %	Additional display, %	No response, %
1	Altitude	96**	26	22	48	4	0
2	Emergency status	83**	30	26	17	4	22
3	VFR/IFR	83**	35	9	35	13	9
4	Ground track	83**	26	9	43	0	22
5	Ground speed	78**	13	0	70**	0	17
6	Weight class	78**	9	9	61**	0	22
7	Flightpath history	74*	48	4	4	4	39
8	Relative altitude	70	39	0	30	0	30
9	Climb/descend	65	22	4	43	9	22
10	Sequence number	65	9	22	65**	4	0
11	Identification	61	22	22	48	9	0
12	Heading	61	35	4	43	4	13
13	Assigned runway	57	9	0	61**	9	22
14	Vertical speed	52	4	4	35	9	48
15	Assigned altitude	43	4	4	30	13	48
16	Destination airport	43	4	9	57**	13	17
17	Aircraft type	39	9	9	35	13	35
18	CDTI or not	35	4	4	39	4	48

* = 99% level of confidence.

** = 95% level of confidence.

significant number of pilots, except for symbolic representation of the flight-path history. Virtually none of the pilots felt that information about the status of other aircraft should be presented on an additional display. As many as 48% of the pilots did not select any display format for low-priority items.

Information selection method- Seventy-eight percent of the pilots indicated that they preferred a touch-sensitive display to request a block of information about the status of another aircraft. None of the other options presented in table 4 was selected as a first or second choice by more than 13% of the pilots.

TABLE 4.- DATA BLOCK SELECTION METHOD

Percent of pilots who selected each method as a first or second choice	Method of selection
78	Touch-sensitive display
13	Single button to request data blocks on all aircraft
13	Keyboard entry of aircraft i.d. for data on a single aircraft
9	Buttons along display to request data on all aircraft in a specific area
9	A single switch to request different levels of complexity of information on all aircraft

Data block format- Ten examples of data blocks that depicted different amounts and types of status information were shown to the pilots. They were asked to select which, if any, they would want displayed: (1) permanently for all aircraft; (2) at pilot request for all aircraft; and (3) at pilot request for a single aircraft. Less than 22% of the pilots selected any one data block format for permanent display or at pilot request for all aircraft. Forty percent of the pilots did not want any type of data block if it was to be displayed beside all aircraft within the range of the map at the same time. If the data block was to appear at pilot request for a single aircraft, however, 69% selected the sample data block that displayed: (1) Identification; (2) Altitude; (3) Assigned altitude; (4) Direction of flight (climb/descend); (5) Vertical speed; (6) Heading; (7) Ground speed; (8) Landing sequence number; and (9) Destination airport. Most of the pilots (83%) did not want the units of measurement (feet, knots, etc.) in the data block. Several of

the pilots suggested that the information presented in a data block should vary with phase of flight.

They indicated that information missing from a data block should be represented by a row of "XXXs" (43%) or a black space (56%). A significant number of pilots (87%) also felt that a warning message should appear automatically in the data block position if the radar track of an aircraft is lost or if the information is unreliable.

Monochromatic vs Multicolor Displays

After seeing a number of the monochromatic displays presented next to the same displays in three colors, there were no pilots who said they did not want multicolor displays in the cockpit and only two pilots who felt that they did not need color (table 5). It was clear that pilots thought color coding was

TABLE 5.- PERCENT OF PILOTS WHO FELT MULTIPLE COLORS ON A CDTI ARE NECESSARY OR DESIRABLE TO PERFORM DIFFERENT FLIGHT-RELATED TASKS

Task performed	Percent of affirmative responses
Information recognition (speed)	100**
Information recognition (accuracy)	100**
Distinguishing traffic from other categories of information	96**
Distinguishing terrain from other categories of information	96**
Distinguishing weather from other categories of information	91**
Separation assurance	91**
Determining position of other aircraft	87**
Reading data tag information	83**
Determining intent of other aircraft	70

** = 95% level of confidence.

essential for information recognition, accuracy, and speed; discriminating among the symbols representing terrain, weather, and other aircraft; maintaining separation; and determining the position of other aircraft. Eighty-seven percent of the pilots reported that color coding decreased display clutter.

Color coding was chosen as the preferred method for distinguishing weather (65%) and terrain (52%) from each other and from all other types of information (fig. 30). An equal number of pilots selected color and symbol encoding as means of distinguishing one's own aircraft from other aircraft and one's own route from other routes, but felt that nav aids, intersections, and other specific points should be identified by labels. Color coding was generally preferred alone or in combination with symbol configuration to facilitate recognition and comprehension of information presented.

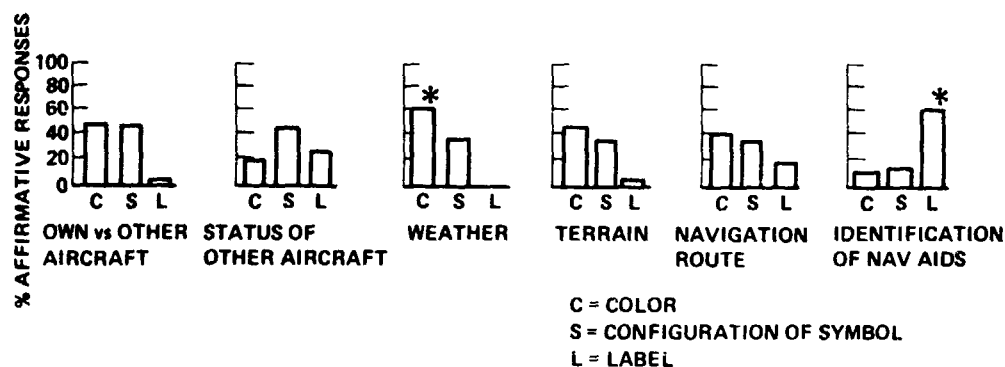


Figure 30.- Preferred format for distinguishing different categories of information from each other.

Concluding Questions

At the conclusion of the study, the pilots were asked to express their opinions about the potential effect of CDTI and about several items that had not been presented.

Map scale- The pilots were evenly divided in their opinions about whether map-scale changes should occur in discrete steps or continuously. A significant number of pilots (78%) responded that map-scale changes (discrete or continuous) should be determined by the speed and altitude of their own aircraft.

Display size- A significant number of the pilots (61%) responded that the minimum acceptable vertical and horizontal dimension for a CDTI is 9 in. (fig. 31), which was the largest option provided. Only 30% of the pilots felt that a 7-in. display would be acceptable, and only 7% considered 5 in. to be an adequate size.

General opinion about CDTI- Although a significant number of pilots (74%) felt that a CDTI might increase their workload somewhat, none felt that their

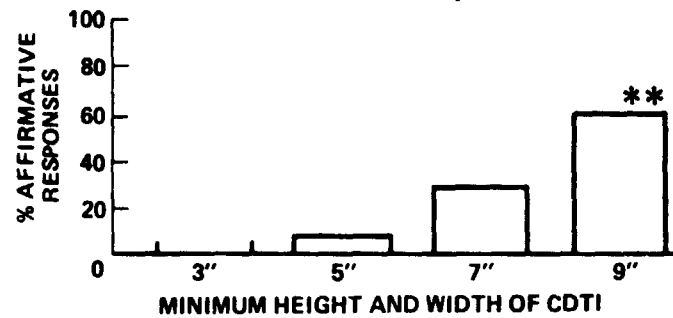


Figure 31.- Pilot opinion about the minimum acceptable size for a CDTI.

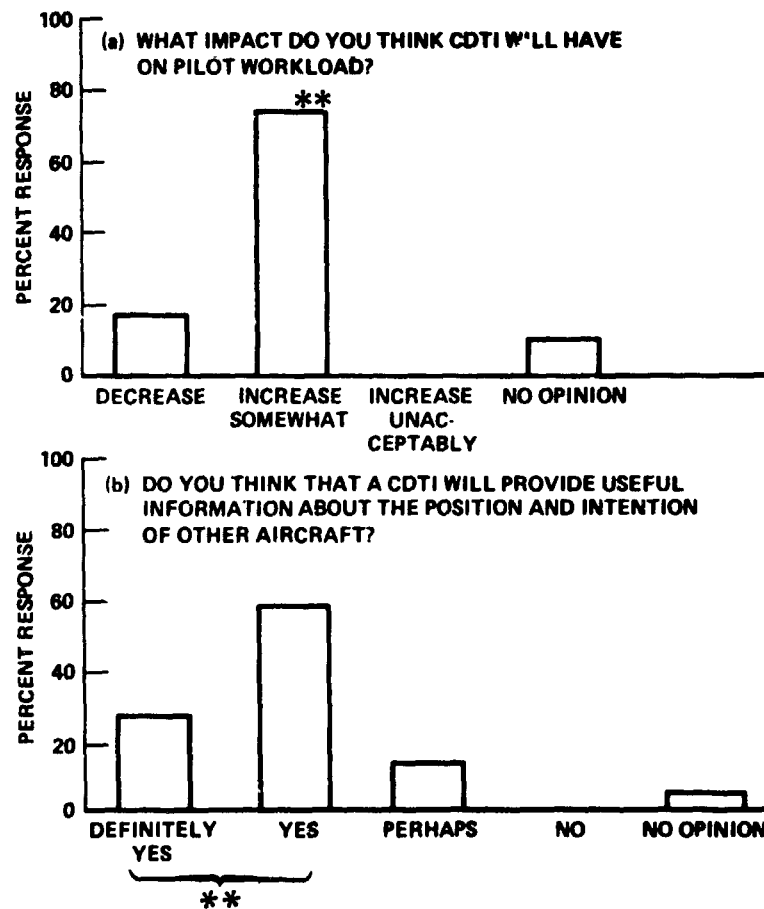


Figure 32.- Pilot responses to questions about the potential effect of CDTI.

workload would increase to unacceptable levels and 17% felt that their workload might decrease (fig. 32(a)). A number of pilots commented that any increase in workload would most likely diminish after the initial familiarization period and two of them added that if there were an increase in workload, "It would be worth it." Several of the pilots commented that the CDTI must serve as a fundamental instrument combining several functions if the pilot's workload is to be reduced and flight safety effectively enhanced. Only one pilot expressed concern that a CDTI would keep his attention confined to the cockpit.

Nineteen of the 23 pilots responded that the CDTI would provide useful information about the position and intention of other aircraft. Three of the remaining pilots agreed, but qualified their answer with concern about display clutter and their reluctance to have an additional single-purpose display included in their cockpit. One pilot did not respond to this question (fig. 32(b)).

CONCLUSIONS

The results of this survey suggest that there is considerable agreement about preferred display content, format, and symbology among professional air carrier pilots. The pilots' responses should only be used as the basis for further research in which the display options for which they expressed a preference are presented to additional pilots in a dynamic simulation environment. This simulation research should determine whether the options for which pilots expressed a preference in static displays also contribute to efficient and accurate performance with minimal increase in pilot workload when presented in a more realistic dynamic environment. In addition, other options, such as map scaling, map orientation, and flightpath predictors, which can only be presented dynamically, should be studied. It is anticipated that recommendations about optimal information content, display format, and symbology for a candidate CDTI can be made at the conclusion of such simulation research.

In the following section, the opinions expressed by a significant number of pilots included in this study will be summarized. In addition, three CDTI configurations have been created that include all of the display elements that a significant number of pilots felt should be included for a 4-mile (fig. 33), 32-mile (fig. 34), and 128-mile (fig. 35) map scale.

It is essential that any conclusions that the reader may draw from these results take into account the limitations of the research methodology: (1) the displays were presented statically; (2) the pilots could neither interact with the displays nor use them in an operational environment; (3) the results reflect subjective evaluations rather than objective measures of performance; and (4) because it was impossible to present all of the possible format and symbology options and combinations of options, other alternatives may exist that the pilots would have chosen had they been given the opportunity.

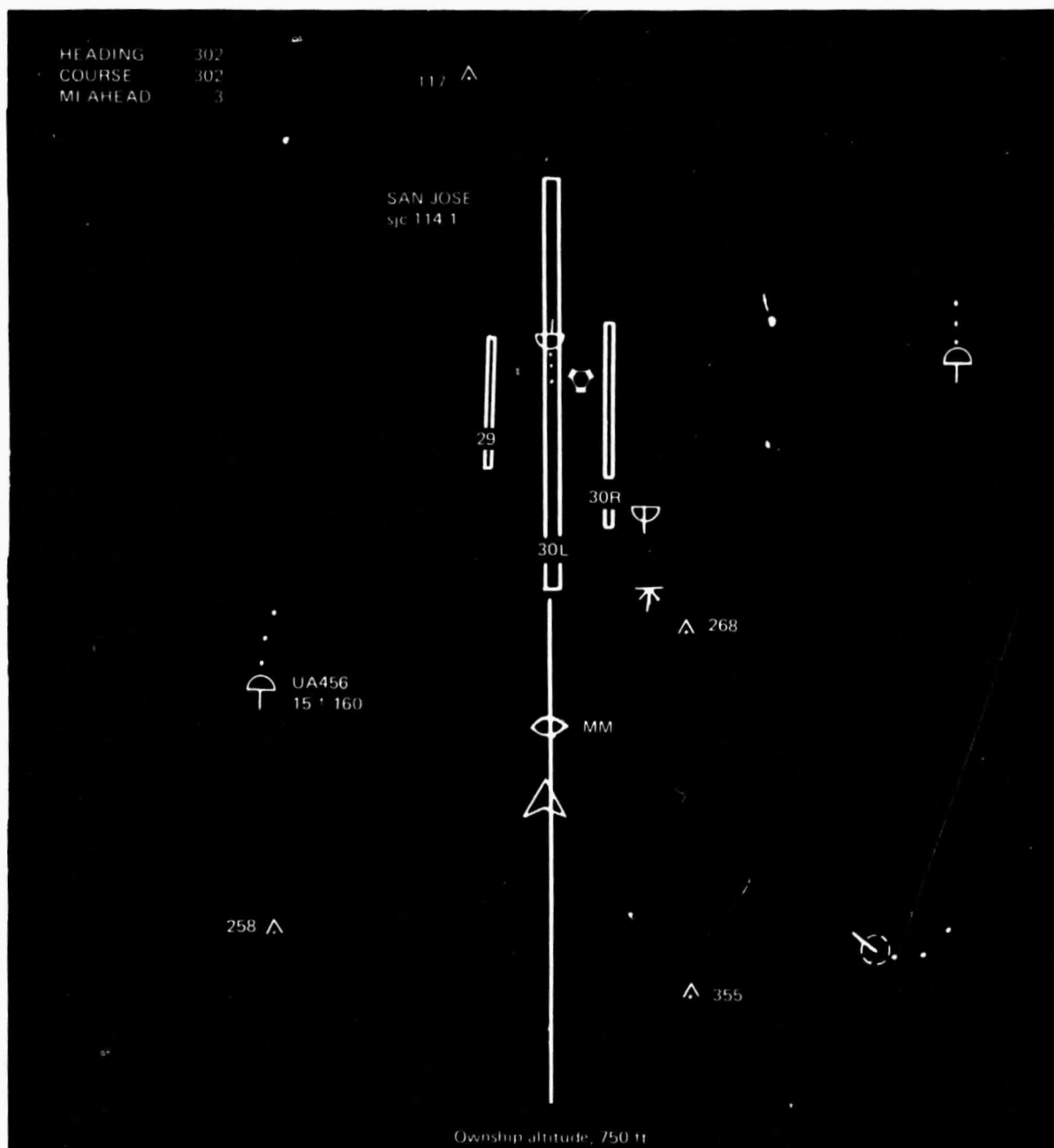


Figure 33.- Graphic summary of pilot-preferred content, format, and symbology for a CDTI: 4-mile map scale for southern approach to San Jose Municipal Airport (own altitude = 750 ft).

HEADING 303
 COURSE 302
 MI AHEAD 21

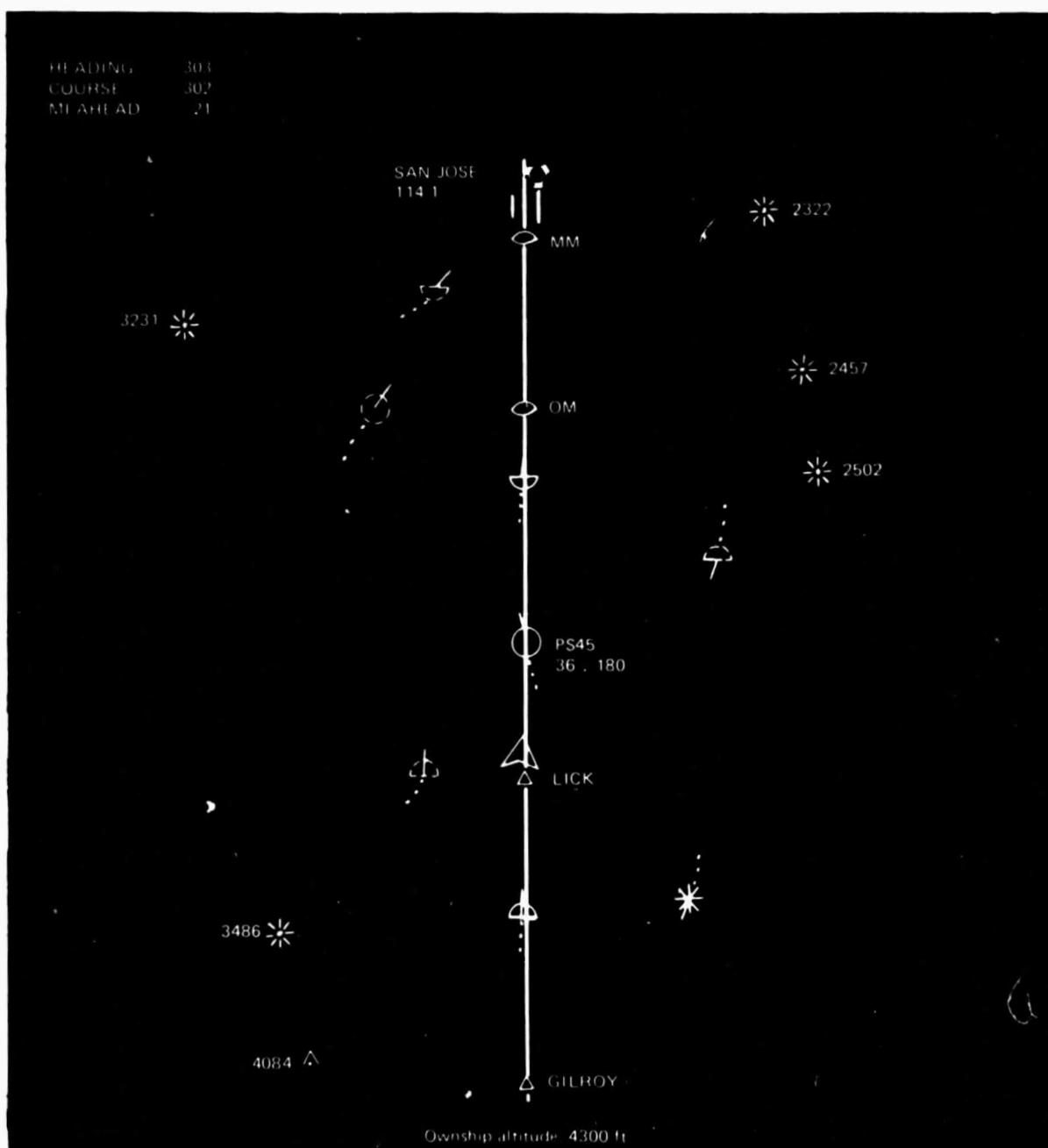


Figure 34.- Graphic summary of pilot-preferred content, format, and symbology for a CDTI: 32-mile map scale for southern approach to San Jose Municipal Airport (own altitude = 4,300 ft).

HEADING 310
 COURSE 302
 MI AHEAD 80

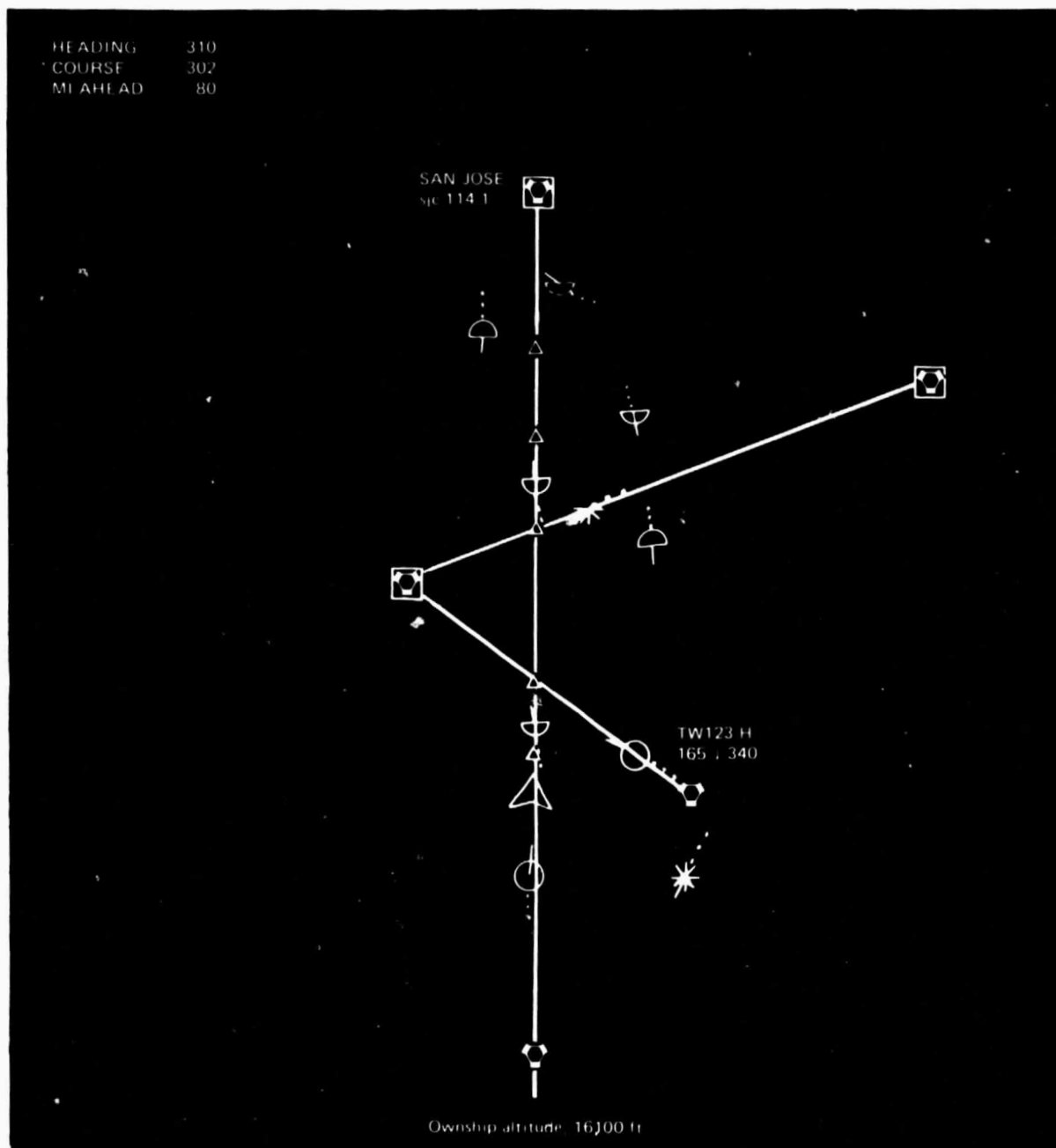


Figure 35.- Graphic summary of pilot-preferred content, format, and symbology for a CDTI: 128-mile map scale for southern approach to San Jose Municipal Airport (own altitude = 16,100 ft).

Navigation Display

The pilots indicated that the proportion of routes displayed should increase as the range of the map is increased (e.g., own route only for 1- to 10-mile map scale, own and intersecting routes for 10- to 50-mile map scales, and either own and intersection routes, or all routes within the range of the map, for map scales greater than 50 miles. Primary nav aids, intersections, and airports should be displayed symbolically. Identifying labels should be included for intermediate map scales. A digital indication of direction of flight and map scale should be included for navigation. Airport control zones, taxiways, and TCA's should not be displayed. The pilots emphasized that only essential information for navigation should be displayed routinely (e.g., own route, perhaps adjacent routes, primary intersections, nav aids, and airports) with additional information available at pilot request.

Terrain Display

All but one pilot felt that significant terrain features should be included in a CDTI by displaying symbols to represent the location and height of individual obstructions. Half of the pilots felt that a digital readout of the minimum safe altitude for sectors adjacent to own aircraft would be an acceptable alternative to a symbolic display of specific obstructions. If a symbolic display is used, two symbols, one for manmade and another for natural obstructions, would be adequate. Terrain information should be displayed automatically if an aircraft is below the minimum safe altitude and should be available at pilot request as well. Obstructions 2,000 ft or closer should be the only ones displayed.

Weather Display

Few of the pilots thought that a graphic display of weather should be included in a CDTI. If weather is to be displayed on a CDTI, however, the information depicted should include at least a graphic representation of location and intensity, and possibly the nature of the weather. There was no agreement about what the symbolic representation for weather should be. All of the pilots felt that any display of weather on a CDTI should be initiated by the pilot.

Symbology for Own Aircraft

The chevron-shaped symbol was selected by a significant number of pilots to represent their own aircraft. Commonly used stick-figure and triangular symbols were rated as unacceptable by nearly half of the pilots. All but two of the pilots felt that the symbol for their own aircraft should be clearly differentiated from the symbol(s) for other aircraft by size, shape, or color. Most pilots (92%) felt that the symbol for their own aircraft should be positioned on the display so that proportionally more of the area displayed was ahead of their present position in a track-up or heading-up map orientation. A centered location was preferred for a north-up map orientation.

Traffic Display

None of the pilots felt that all aircraft within the range of the map should be displayed routinely. The proportion of aircraft displayed should be limited to those within $\pm 2,000$ ft vertically and adjacent laterally to the position of a pilot's own aircraft.

All of the pilots selected symbols for other aircraft that depicted some other information about the status of other aircraft in addition to position. Most pilots preferred the coding scheme suggested for providing information about the relative altitude of another aircraft that indicated whether the aircraft were at, above, or below their altitude, to one that simply differentiated aircraft at their own altitude from those that were not. Although they preferred the triangular symbol that depicted direction of flight as well as position to one that displayed position only, they thought that encoding information about relative altitude (at, above, or below own altitude) into the shape of the symbol was so important that most of them were willing to forego information about the direction of flight in order to obtain it. The pilots' responses indicate that they would have preferred a symbol that combined information about direction of flight, ATC status, flightpath history, and relative altitude (at, above, below), had such an alternative been available.

A significant number of pilots felt that information about the altitude, ground speed, ground track, weight class, ATC status, flight history, and emergency status of other aircraft should be available. At least 60% also felt that information about the direction of vertical flight (climb/descend), sequence number for landing, and identification should be provided. Digital blocks of information for specific aircraft, displayed at pilot request by touch-sensitive displays or automatically (as a warning of proximity or unreliable information), and coded symbols were the preferred sources of status information. Few pilots felt that data blocks should be displayed for all aircraft at all times. Only one or two thought that an additional alphanumeric display would be an acceptable means of providing information about other aircraft.

Use of Color

All of the pilots felt that color coding, to differentiate among categories of information, was essential for speed and accuracy of recognition. They selected color encoding rather than symbol configuration or labels to distinguish weather or terrain from other categories of information. Both color and shape encoding were selected as means of distinguishing own from other aircraft and own route from other routes. Labels were preferred for identifying nav aids.

Display Size

More than 60% of the pilots expressed the opinion that the minimum acceptable size for a CDTI was 9 in.; only one pilot thought that a CDTI should be less than 7 in.

Opinions About the Potential Effect of CDTI

None of the pilots felt that the additional task of monitoring a CDTI would increase his workload to unacceptable levels. Although 74% felt that their workload might increase somewhat, particularly during the initial introduction of CDTI, the consensus seemed to be that the value of the information presented would be such that "It would be worth it." All but four pilots felt that a CDTI would provide useful information about the position and intentions of other aircraft. Three additional pilots felt that the information provided would be useful if, and only if, the display was a fundamental instrument that combined multiple functions and categories of information.

Even though the pilots orally volunteered a concern about display clutter during the experiment, most of them indicated in writing that a great deal of information should be made available for display on a CDTI. Their solution to this inconsistency was to allow the pilot to have control over the amount, type, and complexity of the information displayed at any time. The pilots felt they should be able to select additional information about navigation, terrain, and the status of other aircraft, and any information about weather, by touch-sensitive displays, keyboard entry devices, dials, or buttons. A potential problem with this, which will have to be evaluated experimentally, is that the pilots may not wish to devote as much time as may be required to interact with a CDTI in this manner. A possible alternative solution would be to provide information necessary for different phases of flight automatically, with pilot override for individual components. It is also possible that the pilots may revise their opinions about the amount and complexity of the information to be displayed after they have used such a display in a dynamic simulation. For these reasons, it must be emphasized again that the results of this study reflect pilot opinions only, and that different results may be obtained when the pilots can use different displays in simulated flight.

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